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HEX BALL TORQUE TEST

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Structures and Propulsion Laboratory
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16. ABSTRACT

A series of torque tests were performed on four flight-type hex ball universal joints in order to characterize and determine the actual load-carrying capability of this device. The universal joint is a part of manual actuation rods for scientific instruments within the Hubble Space Telescope. It was found that the hex ball will bind slightly during the initial load application. This binding did not affect the function of the universal joint, and the units would "wear-in" after a few additional loading cycles. The torsional yield load was approximately 50 ft-lb, and was consistent among the four test specimens. Also, the torque required to cause complete failure exceeded 80 ft-lb. It is concluded that the hex ball universal joint is suitable for its intended applications.

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DEFINITION OF SYMBOLS AND ABBREVIATIONS

SI	Scientific Instrument
FGS	Fine Guidance Sensor
OTA	Optical Telescope Assembly
ft-lb	foot-pound of torque
in-lb	inch-pound of torque
CW	clockwise
CCW	counterclockwise
MoS_2	molybdenum disulfide
τ	shear stress
f_{sy}	shear yield stress
f_{ty}	tensile yield stress
KSI	stress, thousand pounds per square inch
T	torque
J	polar moment of inertia
C	distance from centroid to point of maximum shear stress (= radius for circular specimen)
D	outer diameter of specimen
d	inner diameter of specimen
MSFC	Marshall Space Flight Center

TECHNICAL MEMORANDUM

HEX BALL TORQUE TEST

I. INTRODUCTION

The purpose of these tests was to characterize the function of and to determine the load-carrying capability of the hex ball universal joint, Perkin-Elmer part number 679-0760. This universal joint is installed in a total of 17 locations within the scientific instruments (SI) and focal plane structure of the Hubble Space Telescope. It is used in the manual actuation rods for the axial SI, radial SI and FGS point "A" latches, and in the radial SI blind-mate electrical connector. Although the actuation rods had previously been qualified for the maximum specified load of 35 ft-lb, higher loads have been anticipated. Further testing was necessary to prove the structural integrity of the rods and to establish the actual margins on yield and ultimate load.

II. APPROACH

A test fixture was designed to apply torque to the universal joint in a controlled manner. Angular deflection was measured using a digital inclinometer readout. Visual examinations and dimensional checks were made at several times throughout the course of testing, and photographs of the test articles were obtained. Two universal joints were subjected to life cycle testing, and all four test specimens were loaded to the maximum specified load of 35 ft-lb. The units were subsequently loaded to increasingly higher values until an indication of yielding was obtained. Finally, each specimen was tested to destruction.

A. Scope

These tests were not intended as a formal qualification of the universal joint; rather, the tests were for engineering information. Therefore, the test procedure was unreleased, and testing was performed in an engineering laboratory without MSFC Quality Assurance surveillance. However, to assure that the results were valid and representative for the flight hardware, all test instrumentation was within the current calibration period and all test specimens were fabricated per MSFC quality assurance requirements.

B. Test Hardware

Four test specimens were fabricated per the Perkin-Elmer drawings, except the microseal coating on the hex ball was not applied. This exception was specified in the procurement contract for these parts. All material, heat treatment, and dimensional requirements were verified per MSFC quality assurance standard practice. Figure 1 is a photograph of the hex ball and hex ball housing, and Figure 2 shows those pieces assembled as the universal joint.

C. Test Procedure

The tests were conducted per the test procedure, included as Appendix A of this report, with some minor exceptions or modifications which are described in the "Discussion of Test" section.

D. Test Setup

A photograph of the test fixture is included as Figure 3 of this report.

III. SUMMARY OF RESULTS

The test results were consistent for all four specimens. The corners of the hex ball bind slightly in the hex ball housing during the initial load application, but will "wear-in" after a few loading cycles. This binding does not affect the function of the universal joint. The hex ball begins to yield at approximately 50 ft-lb, with permanent deformation occurring both at the reduced diameter "neck" behind the hex ball, and at the edge of the keyway along the shank of the hex ball. Ultimate failure in shear occurs at the neck, at a torque in excess of 90 ft-lb.

IV. DISCUSSION OF TEST

Testing was performed per the run numbers listed in the test procedure, Appendix A of this report. The various test runs are discussed in the following paragraphs in the sequence in which the events occurred. During the course of testing, several changes to the test setup, load application techniques, and data recording requirements were implemented in order to facilitate the successful completion of the tests. These changes are described in the discussion also.

Figure 3 is a photograph of the setup, and a diagram of the overall test setup is shown in Figure 4. The bellcrank/turnbuckle system did not allow sufficient adjustment to always maintain the claw uniformly seated on the handle of the torque wrench. At various times during the testing, small slippages occurred at this interface. Several of the plots of torque-versus-twist show one or more obvious erroneous data points, which are attributed to such movements in the fixture. The test setup also included a metal protractor and pointer as an alternate measurement of twist angle. However, the pointer attachment to the socket wrench extension allowed additional deflection which was not measured by the digital inclinometer. Also, the readability of the pointer/protractor was too coarse to correlate with the inclinometer. Therefore, the twist angle results are taken only from the inclinometer measurements.

Run No. 1 commenced on July 9, 1985. Specimen No. 1 was installed in the test fixture (Fig. 5) and initial readings were taken with the torque wrench attached, and hanging under its own weight while attached to the adapter. The torque reading in this condition was 1.5 ft-lb. This arrangement is referred to as the "slack" condition, and is the typical configuration for beginning and ending data points for all test runs. The unit was torqued clockwise and data was recorded at 5 ft-lb increments up to 35 ft-lb. The digital readout for the torque wrench was switched to the "track" mode, and the applied torque was relaxed to the initial position, with data recorded at 5 ft-lb increments. A copy of the recorded data (Table 1 of the test

procedure) is included as Appendix B of this report. Plotted data is included as Appendix C. Specimen No. 1 was removed from the test fixture and visual and dimensional inspections were performed. Pre- and post-test data were recorded on a copy of Figure 1 of the test procedure. This data is included in Appendix D of this report. Figures 6 and 7 are photographs of specimen No. 1, taken after run No. 1. Wear marks on the hex ball and burnishing within the hex ball housing can be seen.

For run No. 2 and subsequent runs, the torque wrench was recalibrated to read in inch-pounds for more precise readings. Run No. 2 was conducted in the same manner as the first run, except the maximum applied torque was 480 in-lb (40 ft-lb), which corresponded to the value which had been proposed by Perkin-Elmer as a latch breakaway torque. Reference Proposed Interface Revision Notice (PIRN) No. 1377 to the Space Telescope Interface Control Document ST-ICD-01. Recorded torque and angle measurements are given in Appendix B, and plotted data is included as Appendix C. Note that a single bad data point was taken at the 360 in-lb reading. As mentioned before, this is attributed to slippage of the turnbuckle on the torque wrench, and should be disregarded.

Run Nos. 3 through 7 were a durability test of the hex ball universal joint specimen No. 2, and consisted of 50 clockwise/counterclockwise cycles to a torque of 420 in-lb (35 ft-lb) in each direction. Visual and dimensional inspections were made after each 10 cycles. Copies of the recorded data are included in Appendices D and E. The first two cycles were completed per the description in the test procedure; that is, clockwise loading using the turnbuckle, and counterclockwise loading applied manually. This technique was very inaccurate and difficult to do, so beginning at cycle No. 3, the fixture setup on the bench was reversed to make use of the turnbuckle during the counterclockwise half of each cycle. The testing was continued in this manner through cycle No. 40. The torque/angle measurements were acceptable, but the setup activity was very time-consuming. At cycle 40, the test setup was modified to add a longer turnbuckle which would bear on an adapting piece attached to the spacer block. By lengthening the new turnbuckle, counterclockwise torque could be applied to the wrench without having to disassemble the test fixture every one-half cycle. This "upward push" technique was used for the remaining counterclockwise torque applications. This method introduced a slight moment to the test specimen which caused the wrench adapter to lift off the bracket. For the next durability test, which was run on specimen No. 4, a small plate was added which acted as a "collar" to hold the adapter in line in the bracket. This plate worked very effectively.

During the disassembly following cycle Nos. 1 and 2 (specimen No. 1), it had been observed that the corners of the hex ball had deformed very slightly resulting in the ball binding in the hex ball housing. A side force of 17 lb applied at a moment arm of approximately 0.75 in. (or approximately 12.8 in-lb was required to cause the hex ball to "swivel" in the housing. After initially overcoming the binding condition, the ball could be made to move in the housing with less than 10 lb of side force applied. Such motion is believed to help to "wear in" the corners of the hex ball and does not affect the function of the universal joint. This conclusion is supported by the findings during the disassembly of the durability test unit, Specimen No. 2. Removal of the hex ball from the housing was easier than for specimen No. 1, which had been subjected to only a couple of torque applications.

Also, the wear on the corners of the hex ball specimen No. 2 is indicated by the amount of "dead band" or looseness which can be shown by the change in the initial angle reading for clockwise to counterclockwise torque applications. A small

portion of this "dead band" is due to the clearances at the keyways when the adapter attaches to the hex ball, and the hex ball housing attaches to the fixture base. However, changes in the magnitude of this angle are consistent wih the visual appearance of the wear marks on the corners of the hex ball. It was found that for approximately the first 20 cycles, the looseness would increase. After that, the looseness stabilized and remained nearly constant for the balance of the 50 cycles. This can be seen on a composite plot of three durability cycles, which is included in Appendix E. Clockwise-to-counterclockwise readings within the same cycle can be compared; however, end-to-end comparisons cannot be made because the inclinometer mounting plate did not remain cemented to the adapter throughout the test sequence. This installation had to be made several times, and a note was written on the affected data sheets. However, if the inclinometer to adapter cemented joint was not disturbed, a consistent repeatability of the test setup of less than one degree was obtained.

Run Nos. 8 and 9 were performed on specimen No. 3. Results were consistent with run Nos. 1 and 2. There was no detectable difference between specimens 1 and 3.

Run Nos. 10 through 14 were durability tests performed on specimen No. 4. For this test, Braycote No. 602 lubricant was applied to the hex ball. This lubricant contains particles of molybdenum disulfide (MoS_2) suspended in a perfluorinated polyether-based grease. At the very large contact pressure which is on the corners of the hex ball during torque application, the liquid lubrication of the grease is considered negligible. This lubricant was used to determine if the MoS_2 particles would inhibit the wear which had been observed on specimen No. 2 during run Nos. 3 through 7. On the flight hardware, a dry film MoS_2 coating, Microseal 200, is applied. Post-test inspection of specimen No. 4 indicated smoother wear marks than on specimen No. 2. Also, the looseness indicated by the clockwise-to-counterclockwise "dead band" was slightly less. See the plotted data in Appendix E. These results confirm the conclusion from the first durability test, that wear on the corners of the hex ball does not affect the function of the universal joint.

In run Nos. 15 through 18, each hex ball was torqued in the clockwise direction until an indication of yielding occurred. This point cannot be determined exactly, but can be estimated by the distinct change in slope of the torque-versus-angular deflection plots. Yielding began at approximately 50 ft-lb for each test specimen. See the plotted data in Appendix C. Visual examination of the hex balls after these tests indicated that yielding had occurred in two places, at the "neck" behind the hex ball, and along the edge of the keyway. This result is slightly less than the calculated yield point for the neck area of the hex ball as shown below.

Material: Ph 13-8 Mo, Condition H1000

From MIL-HDBK-5C,

$$f_{sy} \cong 0.55 \times f_{ty} = 105.6 \text{ KSI} = \tau$$

$$T = \frac{\tau J}{c} \qquad J = \frac{\pi (D^4 - d^4)}{32}$$

$$c = 0.320/2 = 0.16 \qquad D = 0.320 \qquad d = 0.112$$

$$T = \frac{(104.5 \times 10^6)\ [\pi\ (0.320^4 - 0.112^4)/32]}{(0.16)} = 662 \text{ in.-lb} - 55.2 \text{ ft-lb}$$

(52.6 ft-lb at minimum B/P diameter).

The initial yielding may have occurred at the keyway, which is of less concern than the neck area behind the ball. Although there was some deformation (and there was difficulty in removal of the hex ball from the adapter), the keyway was able to sustain much higher loading after yielding had occurred.

The remaining runs were to load each hex ball specimen to ultimate failure. However, during run No. 19, yielding of the hex ball-to-wrench adapter occurred at approximately 65 ft-lb; thus, the specimen No. 1 was not taken to ultimate failure on this test run. This unit was later tested to destruction in run No. 23. In order to continue the tests, a one-half inch socket wrench adapter and a three-eighths inch allen wrench bit were used with a second hex ball housing as a replacement for the wrench adapter.

Accurate torque-versus-angular deflection data was not obtained at the ultimate failure point for any of the four specimens. The test fixture was set up to position the torque wrench at a different initial angle. The larger turnbuckle was used for part of the runs, and a switch to the shorter turnbuckle was made when the torque wrench had moved to within the fully extended adjustment of the shorter turnbuckle. At higher loading levels (above 80 ft-lb), the hex ball universal joints exhibited time-dependent load-versus-deflection characteristics. The hex ball would not sustain a specific input torque value, and continued to twist with severe plastic deformation in the neck area. The specimens were able to carry a higher load, however, if the application was a continuously increasing input torque. The load application equipment (turnbuckle, claw, etc.) was not sufficiently stiff to input a specific deflection and hold that position to allow the torque level to stabilize at a lower value (which might have shown as a negatively sloped plot of torque versus angle). Consequently, the angle readings at torque values above 80 ft-lb are questionable. When the range of travel of the inclinometer was exceeded, the cement joint at the attachment to the replacement adapter would become loose. Also, the hex ball did not fail before the full adjustment range of the turnbuckle was taken up. In each case, the ultimate failure load had to be applied manually, and ranged from 91 to 96 ft-lb. Failure occurred at the neck, immediately adjacent to the hex ball. Figures 8 and 9 are photographs of one of the hex balls following the test failure.

V. CONCLUSIONS AND RECOMMENDATIONS

Based on the results of these tests, it is concluded that the proposed maximum torque value of 40 ft-lb per PIRN 1377 can be approved. It is recommended that the torque applied to any of the actuation rods not exceed 45 ft-lb in order to avoid a yield-type failure of the universal joint. It should be noted, however, that the load-carrying capability of the universal joint exceeds 45 ft-lb by a comfortable margin. In a contingency situation, higher torque values may be considered, although some yielding is likely to be sustained.

Figure 1. Hex ball and hex ball housing.

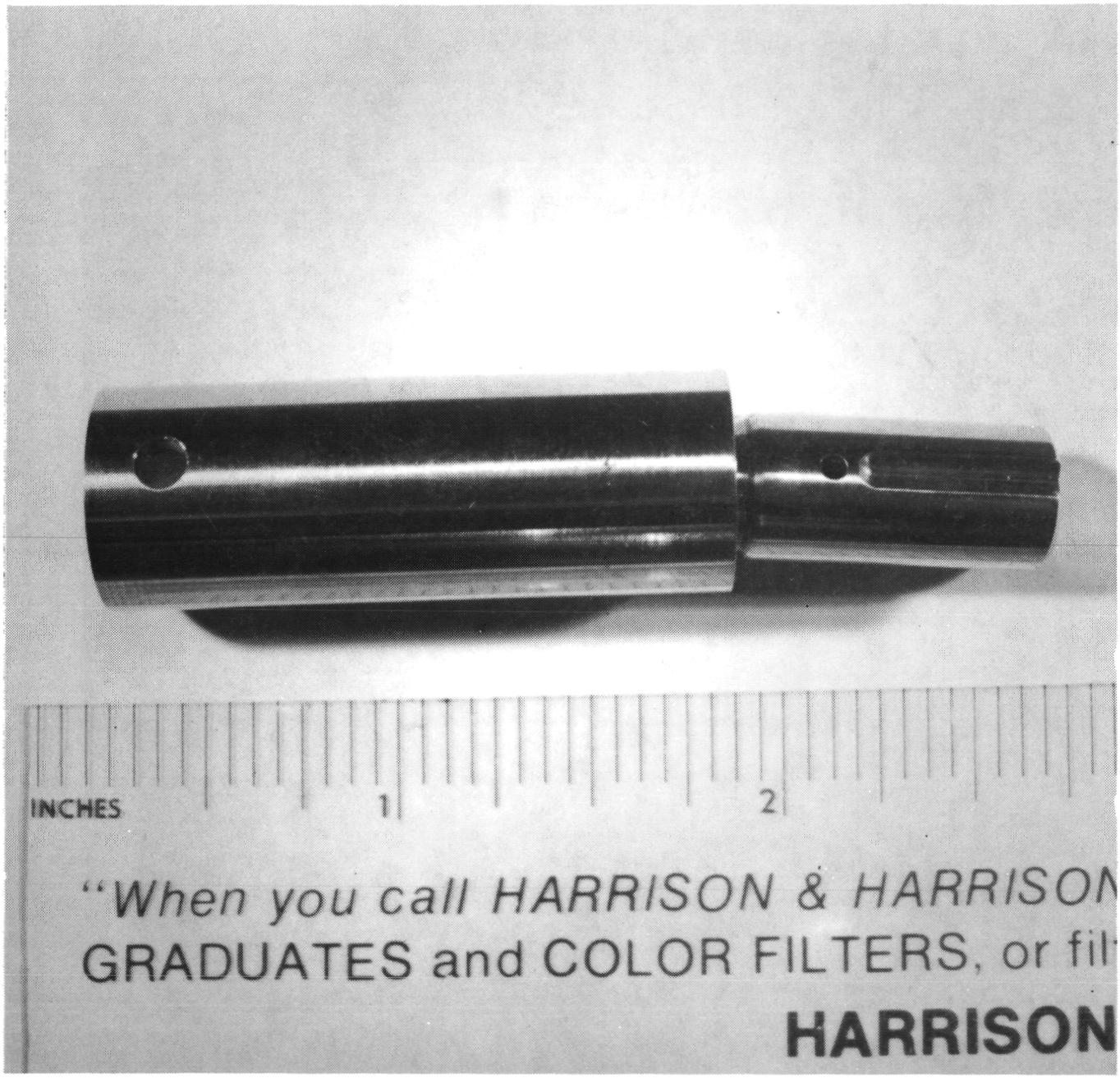

Figure 2. Hex ball universal joint.

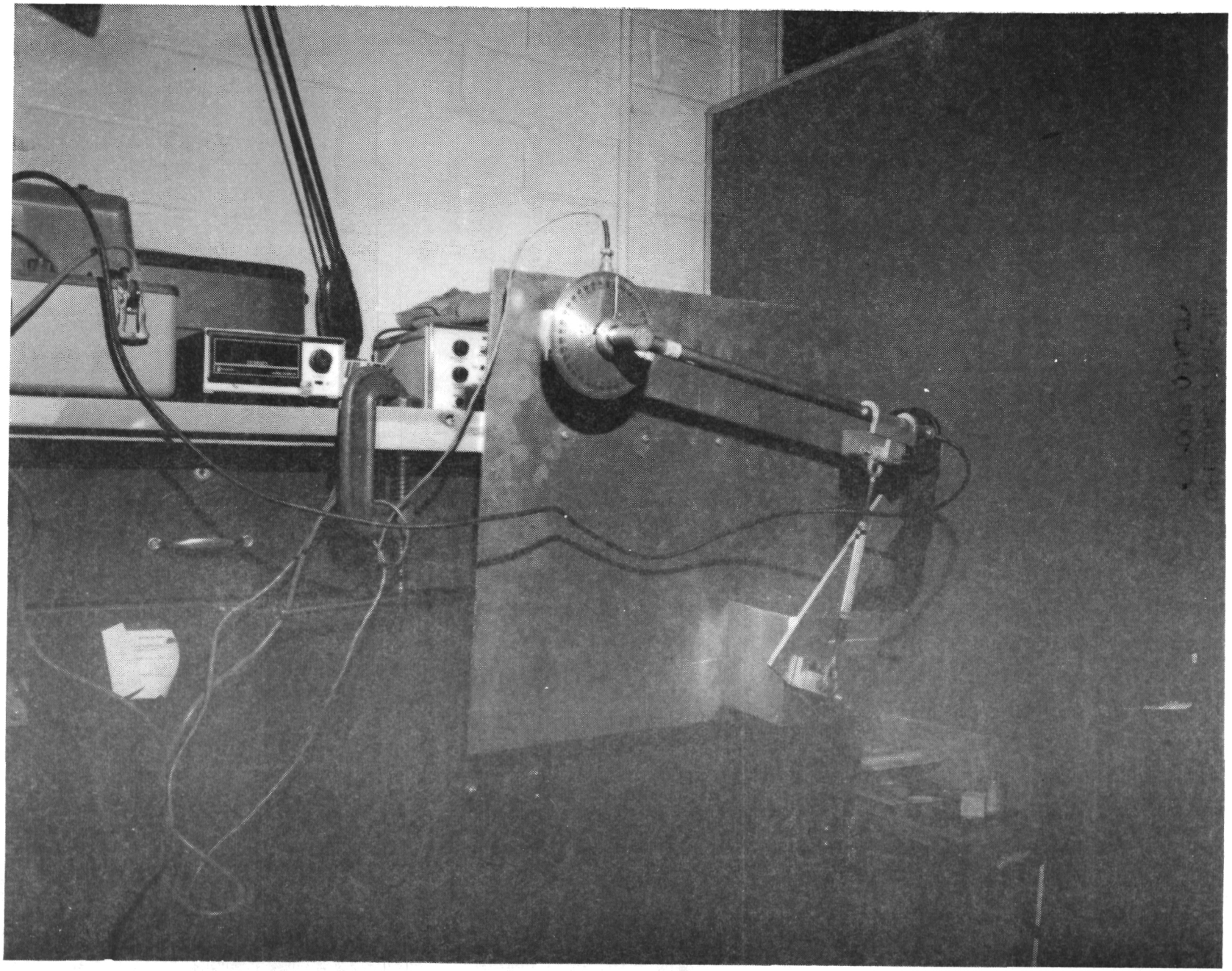

Figure 3. Photograph of test setup.

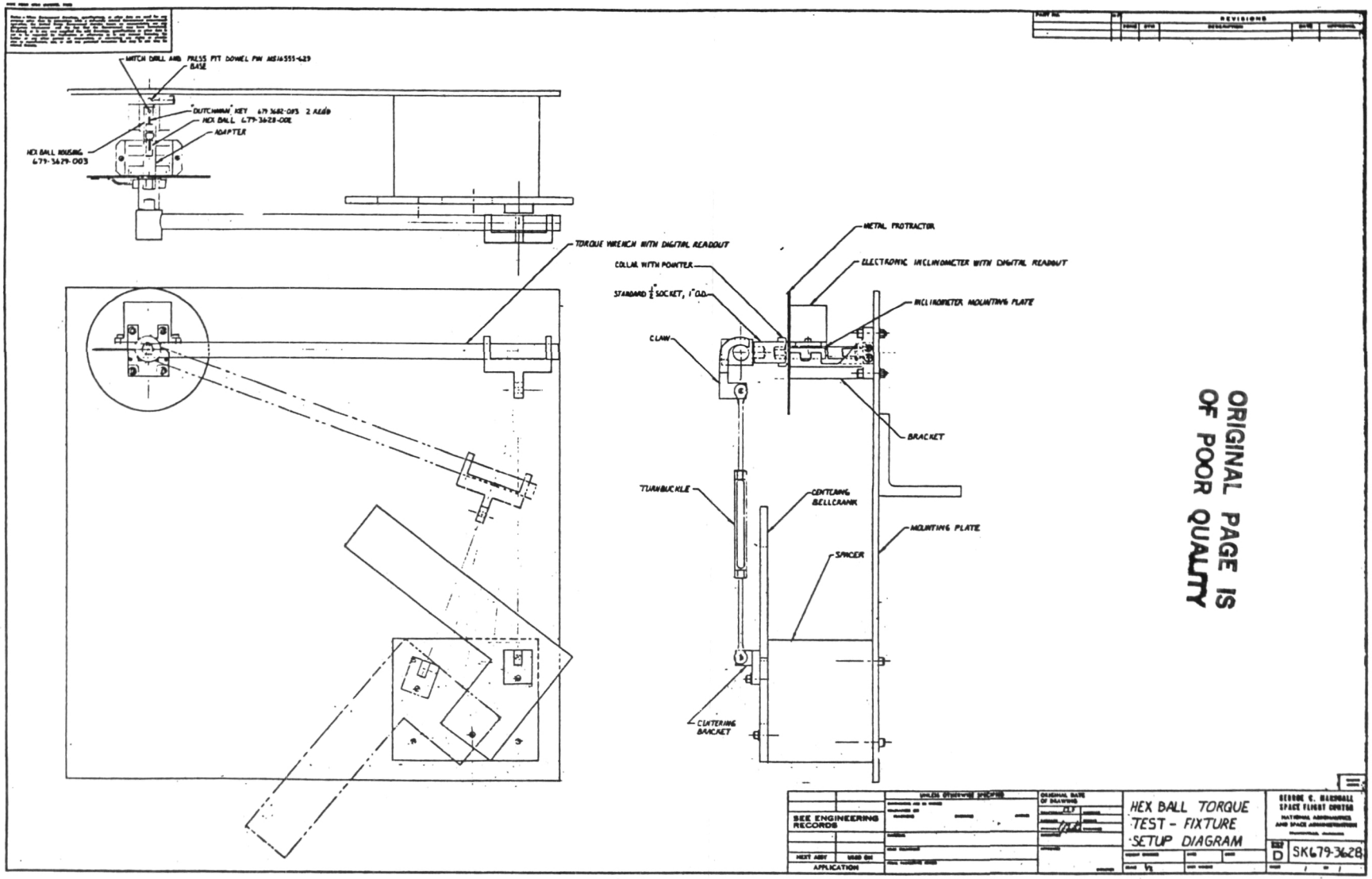

Figure 4. Test setup.

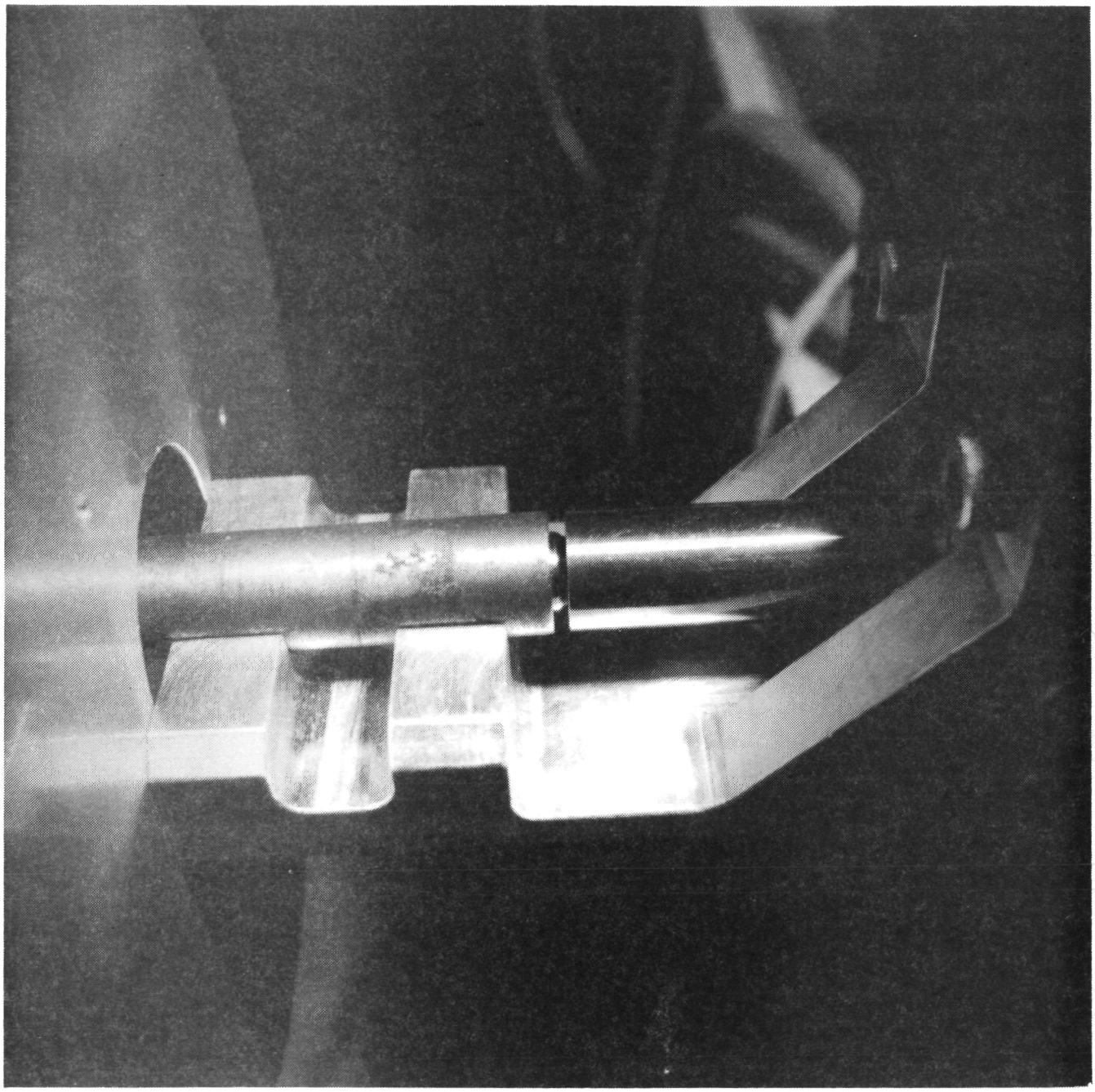

Figure 5. Universal joint installed in fixture.

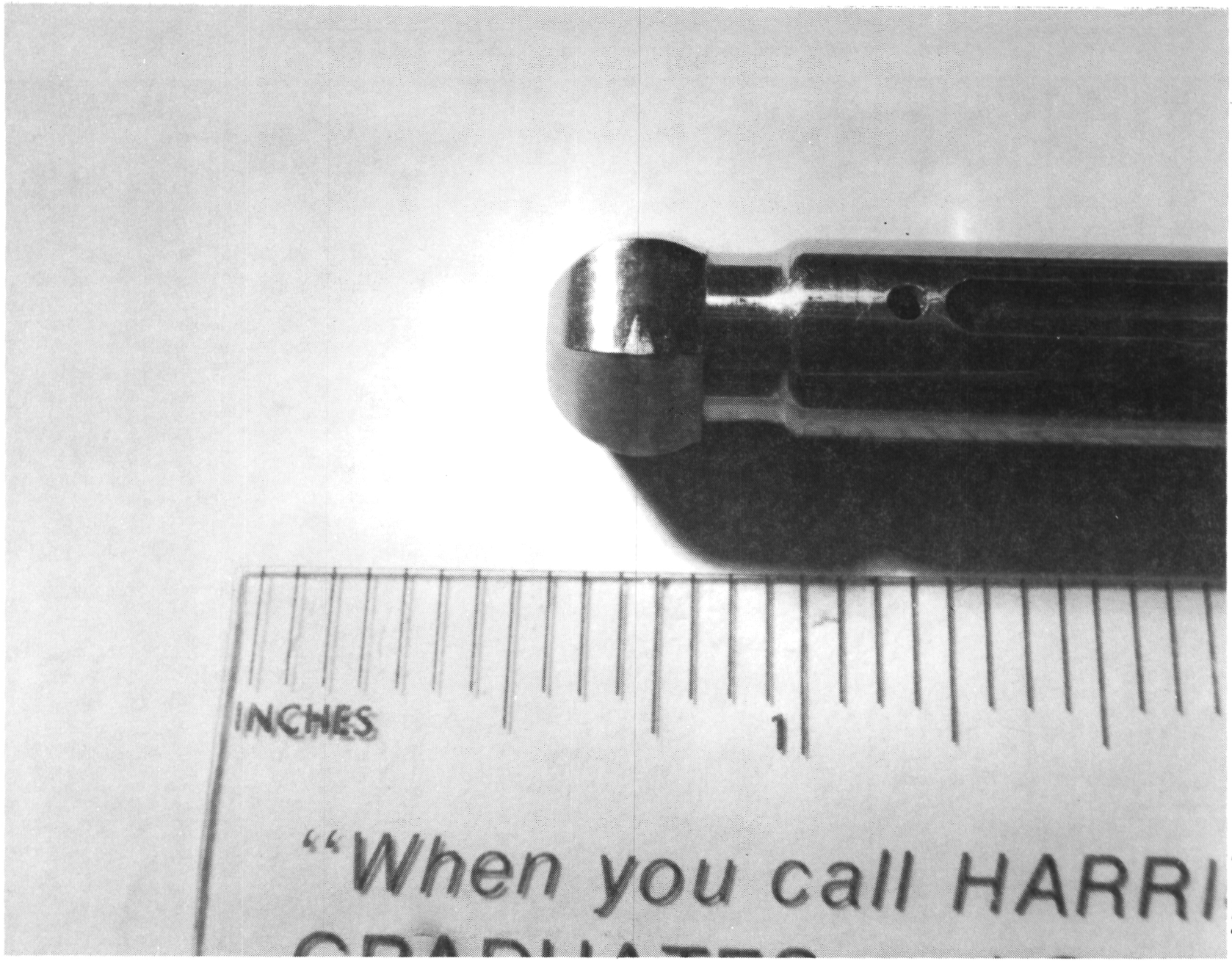

Figure 6. Hex ball after run No. 1.

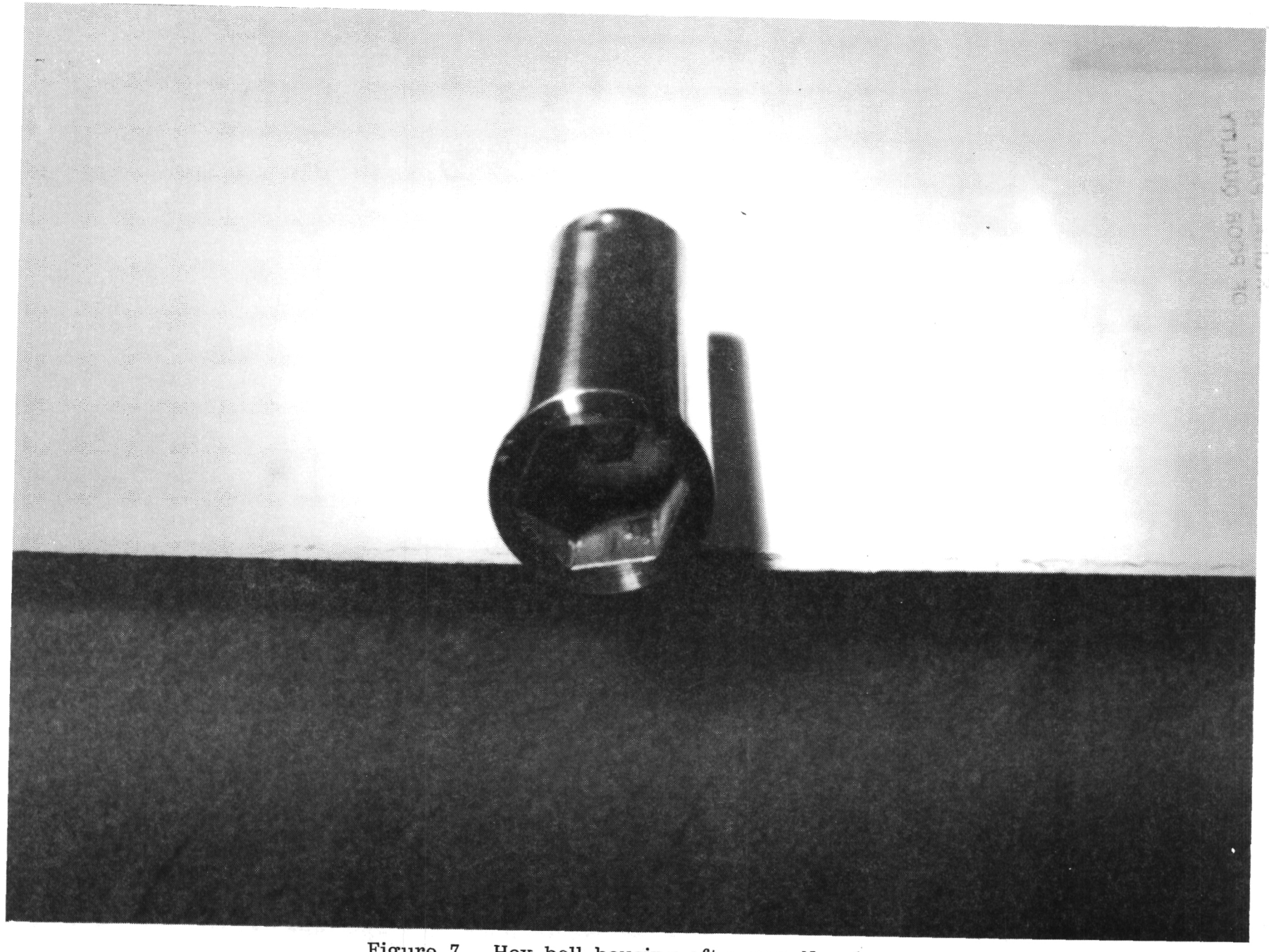

Figure 7. Hex ball housing after run No. 1.

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OF POOR QUALITY

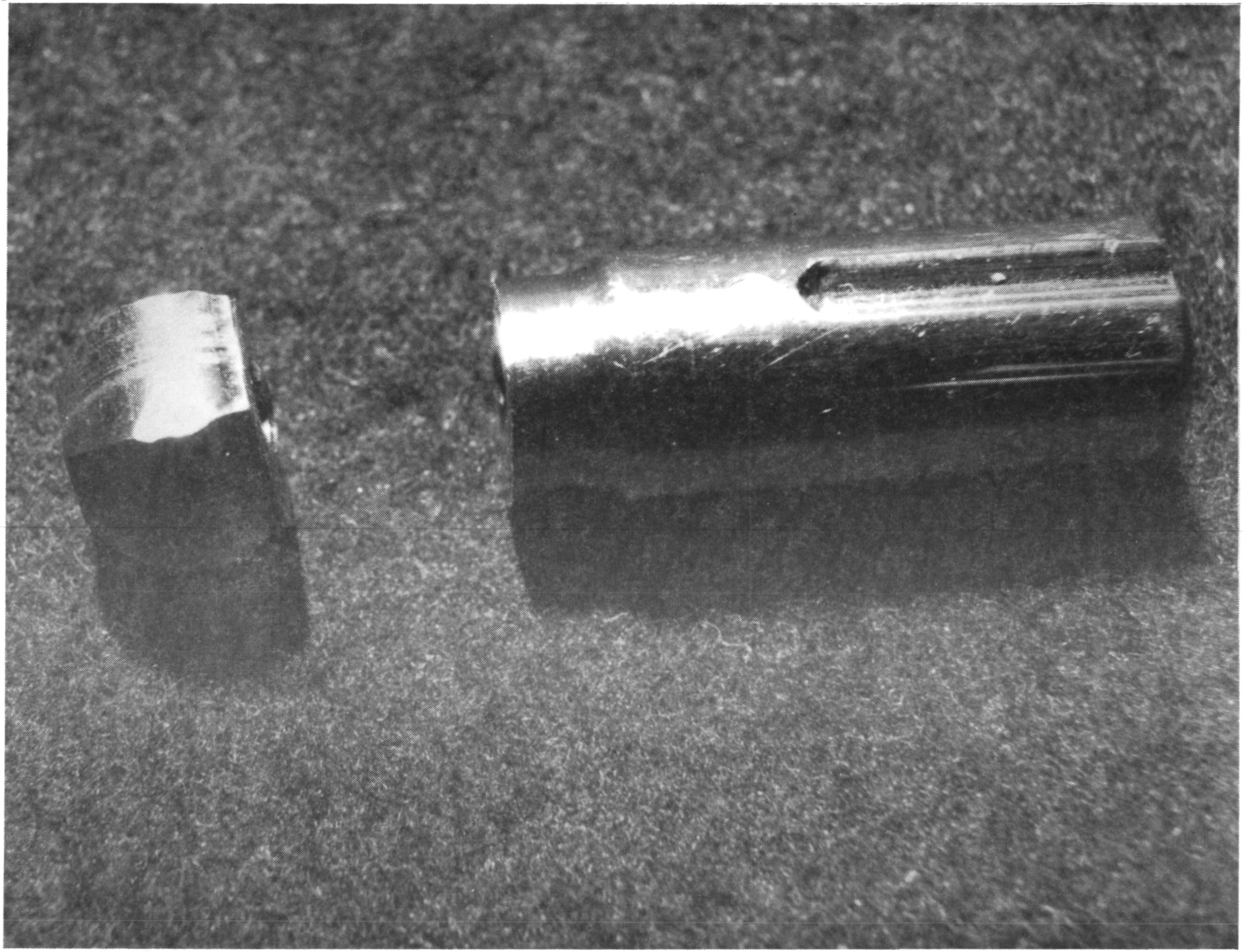


Figure 8. Hex ball after failure.

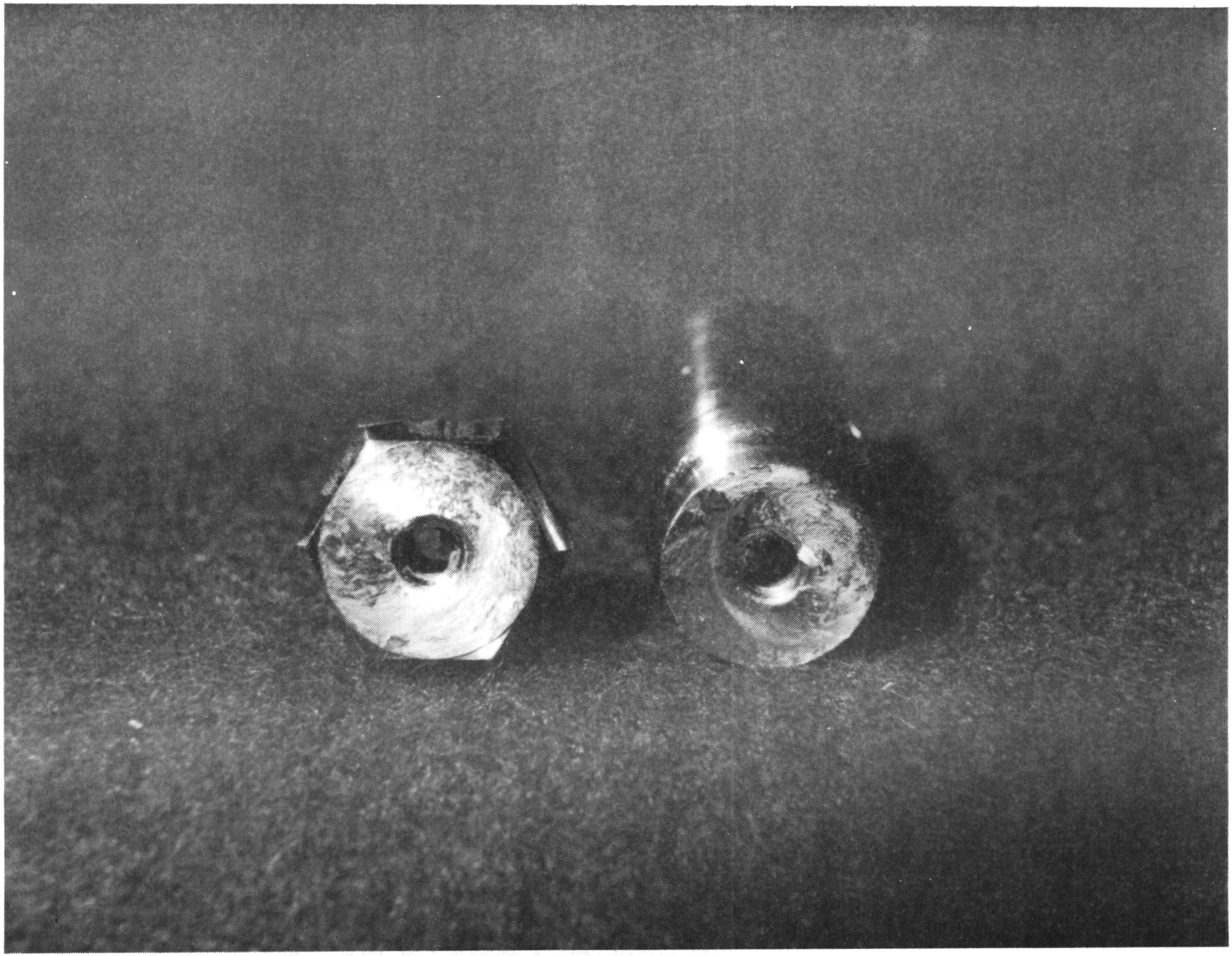


Figure 9. Fracture interface.

APPENDIX A

TEST PROCEDURE

HEX BALL TORQUE TEST

Purpose

A series of torque tests will be performed on representative test specimens to characterize the torque-transmission and wear tolerance of the hex ball universal joint used in various places in manual actuation devices within the Space Telescope OTA. These tests will be carried to destruction to establish the actual maximum torque capability of this universal joint.

Test Hardware

Four (4) specimens, fabricated per Perkin-Elmer drawings, will be tested. The specimens shall be identified as No 1 through 4. MSFC quality assurance verification of materials, heat treat condition, and dimensions is required.

Test Setup

The test setup is shown on drawing SK679-3628. Prior to final assembly of the test fixture, the components shall be fit checked and modified, if required, to meet the intended function. Note: The base includes provisions for match drilling and doweling the hex ball housing in place. The MS16555-629 dowel pin should not be installed unless necessary for stability and repeatability.

Visual and Dimensional Inspection

The hex ball and the hex ball housing shall be visually inspected under 10X magnification, and dimensions shall be measured and recorded on a copy of Figure 1 prior to the start of testing. Any excessive looseness or tightness of the fit of the ball in the housing shall be noted. The ball should be free to pivot within the housing, or should move with slight thumb pressure applied. Any looseness or "play" about the axis of rotation should be noted, along with any difficulty in insertion or removal of the hex ball.

Test Setup Adjustments and Repeatability

Following the preliminary fit check, the fixture shall be set up on a bench and firmly clamped in place. The mounting plate shall be oriented in a vertical plane (as indicated by a carpenter's level). Use shims at interface, if required. Any rotational play in the bracket-to-plate interface shall be taken out in the clockwise direction prior to tightening attachment hardware. Similarly, all play in the test article, adapter, socket, turnbuckle, torque wrench, etc. shall be taken out in the clockwise direction. In this position, the inclinometer and pointer for the protractor shall be zeroed.

After zeroing the angle measurement equipment, the test article shall be removed from the setup, taking care not to disturb the inclinometer-to-adapter or collar-to-socket attachments. The setup shall then be repeated and the inclinometer reading shall be recorded. Repeatability within ±1° is a goal; the actual fixture and test article repeatability is needed to evaluate the test results.

Test

Run No. 1

Verify the fixture is set up and instrumentation is adjusted prior to initial application of torque. The test article shall be test specimen No. 1.

Slowly and uniformly apply torque in clockwise direction, using turnbuckle. Closely observe all components of test setup for abnormal movement or instability. Continuous hands-on support and control may be required, particularly at higher torque values. Pause at 5 ft-lb increments during torque application and record torque value and angle of twist on a test data sheet, Table 1. Continue clockwise torque application up to 35 ft-lb, recording data at each step. Slowly and uniformly relax applied torque, recording data at 5 ft-lb increments. Without disturbing angle measurement equipment, remove the test article from the fixture and perform visual and dimensional inspection. Record results on a copy of Figure 1.

Run No. 2

Repeat above sequence, except maximum torque shall be 40 ft-lb.

Run No. 3

Set up test fixture with specimen No. 2 installed. Zero instrumentation with all "play" taken out in the clockwise direction. Apply torque and record data per run No. 1, above, except upon returning to zero applied torque, do not disturb setup or remove the test article. Record data on a copy of Table 2. Reverse the torque wrench and change the readout instrumentation as required for counter-clockwise torque application. Taken out all "play" in the CCW direction and record, but do not re-zero the inclinometer or pointer. Apply torque (manually, fixture is not configured for turnbuckle use in CCW direction) and record data per Table 2. Note: Bracket-to-plate interface has been adjusted for CW torque application; watch carefully for any slippage at this location. Fixture modification may be required. Repeat CW and CCW torque application to 35 ft-lb for a total of 10 cycles. Do not re-zero inclinometer. "Initial" angle for each cycle will be compared to previous readings for an indication of wear. After 10 cycles, remove the test article and perform the visual and dimensional inspection. Record data per Figure 1.

Runs 4 through 7

Repeat run 3 for a total of 50 cycles on test specimen No. 2. Note: Some of the intermediate data points may be omitted if linearity and hysteresis/repeatability characteristics warrant such.

Runs 8 and 9

Repeat runs 1 and 2, using specimen No. 3.

Runs 10 through 14

Repeat runs 3 through 7, using specimen No. 4. Exception: Apply a small amount of Braycote No. 602 to the hex ball bearing surfaces prior to each sequence of 10 cycles. Note any change in wear indications during visual and dimensional inspections.

Run No. 15

Repeat sequence of steps 1 and 2, except continue beyond 40 ft-lb, in 5 ft-lb increments, until a definite indication of yielding occurs. (Recorded data shall be plotted in real time, and a distinct change of slope shall be regarded as an indication of yielding. The inclinometer will also not return to zero by an amount greater than the established hysteresis and repeatability values.) If possible, try to pinpoint the location of yielding in the test article during the visual and dimensional inspection. Possible locations include: the reduced diameter behind the hex ball; the keyways; on the corners of the flats on the hex ball or hex ball housing.

Run No. 16

Repeat run No. 15 using specimen No. 2. Note any change in yield points in comparison with specimen No. 1.

Run No. 17

Repeat run No. 15 using specimen No. 3. Note any change in yield points in comparison with specimen No. 1 and No. 2.

Run No. 18

Repeat run 15 using specimen No. 4. Again, compare yield with previous specimens.

Run No. 19

Repeat above sequence, except continue torque application until failure occurs. This may be an actual fracture of the test article, or a negative slope on the torque versus angle plot. Note: Inclinometer will not read angles beyond 20°, and manual torque application is necessary when adjustable range of turnbuckle is exceeded.

Run No. 20

Repeat run No. 19 using specimen No. 2. Note any change in failure points for specimen No. 2 in comparison with specimen No. 1.

Run No. 21

Repeat run No. 19 using specimen No. 3. Note any change in failure points for specimen No. 3 in comparison with specimen No. 1 and No. 2.

Run No. 22

Repeat run No. 19 using specimen No. 4. Again, compare failure points.

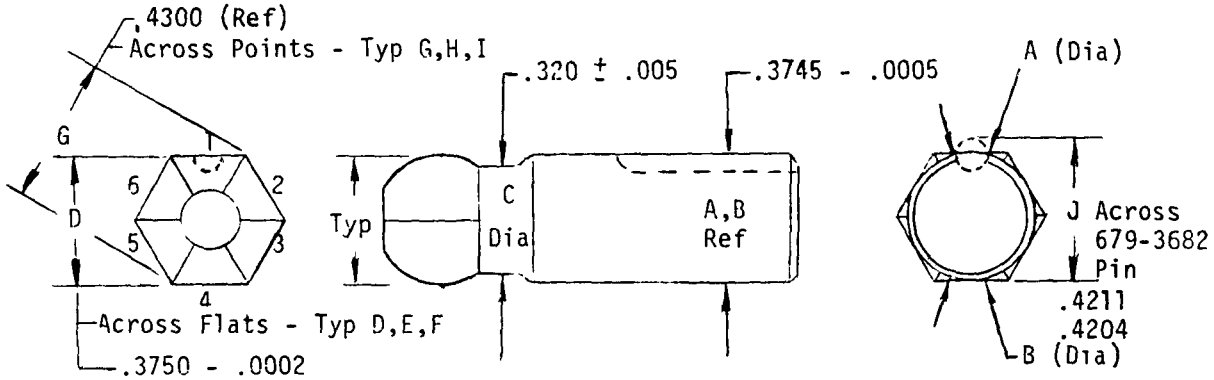
Runs 23 and 24

Assuming the failures occur on the 679-3628 hex balls, and that the 679-3629 hex ball housing is still serviceable, one specimen of the hex ball housing shall be tested to establish the yield and ultimate capability. Using a 3/8 in. allen wrench bit, apply torque per runs 3 and 4. Note: Failure may occur at the keyway of the fixture base. If this occurs, note results and discontinue test.

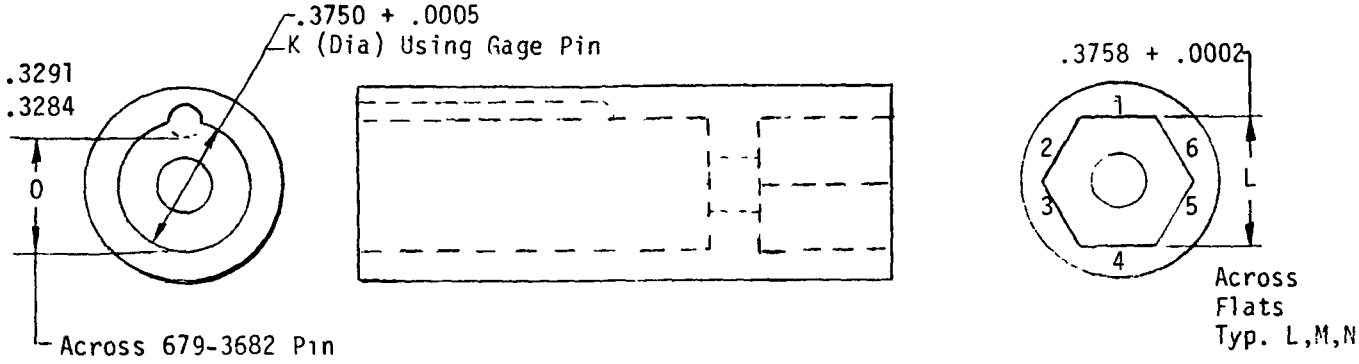
FIGURE 1

Date _____
Hex Ball Specimen No. _____
Hex Ball Housing Specimen No. _____
Run No. _____

DIMENSION	PRE-TEST VALUE	POST-TEST VALUE	REMARKS (Visual Condition)
A			
B			
C			
D (1 to 4)			
E (2 to 5)			
F (3 to 6)			
G (1,2 to 5,4)			
H (2,3 to 6,5)			
I (3,4 to 1,6)			
J			
K			
L (1 to 4)			
M (2 to 5)			
N (3 to 6)			
O			



Hex Ball 679-3628
B/P Dimensions & Tolerances
Shown for Reference



Hex Ball Housing 679-3629
B/P Dimensions & Tolerances
shown for reference

TABLE 1

Date_____
Hex Ball Specimen No._____
Hex Ball Housing Specimen No._____
Run No._____
Direction of Torque Application_____

TORQUE (____)	ANGLE (Degrees)	REMARKS (Record maximum torque applied, any significant observations)

Initial Angle Reading (Repeatability Setup)_____

Final Angle Reading (Repeatability Setup)_____

TABLE 2

Date _____
Hex Ball Specimen No. _____
Hex Ball Housing Specimen No. _____
Run No. _____

Set Point & Direction	CYCLE NO. 1 Applied Torque	CYCLE NO. 1 Angle	CYCLE NO. 2 Applied Torque	CYCLE NO. 2 Angle	CYCLE NO. 3 Applied Torque	CYCLE NO. 3 Angle	CYCLE NO. 4 Applied Torque	CYCLE NO. 4 Angle	CYCLE NO. 5 Applied Torque	CYCLE NO. 5 Angle
0 (CW)										
5 CW										
10 CW										
15 CW										
20 CW										
25 CW										
30 CW										
35 CW										
30 CW										
25 CW										
20 CW										
15 CW										
10 CW										
5 CW										
0 (CW)										
0 (CCW)										
5 CCW										
10 CCW										
15 CCW										
20 CCW										
25 CCW										
30 CCW										
35 CCW										
30 CCW										
25 CCW										
20 CCW										
15 CCW										
10 CCW										
5 CCW										
0 (CCW)										

TABLE 2 (Continued)

Date_____
Hex Ball Specimen No._____
Hex Ball Housing Specimen No._____
Run No._____

Set Point & Direction	CYCLE NO. 6 Applied Torque	CYCLE NO. 6 Angle	CYCLE NO. 7 Applied Torque	CYCLE NO. 7 Angle	CYCLE NO. 8 Applied Torque	CYCLE NO. 8 Angle	CYCLE NO. 9 Applied Torque	CYCLE NO. 9 Angle	CYCLE NO. 10 Applied Torque	CYCLE NO. 10 Angle
0 (CW)										
5 CW										
10 CW										
15 CW										
20 CW										
25 CW										
30 CW										
35 CW										
30 CW										
25 CW										
20 CW										
15 CW										
10 CW										
5 CW										
0 (CW)										
0 (CCW)										
5 CCW										
10 CCW										
15 CCW										
20 CCW										
25 CCW										
30 CCW										
35 CCW										
30 CCW										
25 CCW										
20 CCW										
15 CCW										
10 CCW										
5 CCW										
0 (CCW)										

APPENDIX B

TORQUE, TWIST DATA FROM RAW DATA SHEETS

TABLE 1

Date 7-9-85
Hex Ball Specimen No. 1
Hex Ball Housing Specimen No. 1
Run No. 1
Direction of Torque Application CW

TORQUE (ft-lb)	ANGLE (Degrees)	REMARKS (Record maximum torque applied, any significant observations)
001	+0.039	
005	-0.526	
010	-1.312	
015	-2.019	
020	-2.666	
025	-3.307	
030	-3.972	
035	-4.644	
034	-4.644	Switched to "track"
030	-4.417	
025	-4.113	
020	-3.754	
015	-3.170	
010	-2.352	
005	-1.460	
001	-0.525	Turnbuckle slack
		Inclinometer installation reversed, resulting in negative angle readings.
		Inclinometer cement broke after final reading.

Initial Angle Reading (Repeatability Setup) +0.039

Final Angle Reading (Repeatability Setup) -0.165

TABLE 1

Date 7-10-85
Hex Ball Specimen No. 1
Hex Ball Housing Specimen No. 1
Run No. 2
Direction of Torque Application CW

TORQUE (in-lb)	ANGLE (Degrees)	REMARKS (Record maximum torque applied, any significant observations)
22	-0.27	
60	+0.457	Inclinometer has been set up in reverse
120	+1.237	of Run No. 1, thus the change in sign.
180	+1.932	
240	+2.610	
300	+3.248	
360	+3.380	
420	+4.535	
483	+5.319	
470	+5.324	Switched to "track"
420	+5.092	
360	+4.768	
300	+4.374	
240	+3.871	
180	+3.153	
120	+2.284	
60	+1.306	
22	+0.501	
		Turnbuckle slack

Initial Angle Reading (Repeatability Setup) -0.27

Final Angle Reading (Repeatability Setup) +0.273

TABLE 1

Date 7-30-85
Hex Ball Specimen No. 1
Hex Ball Housing Specimen No. 1
Run No. 2A
Direction of Torque Application CW

TORQUE (in-lb)	ANGLE (Degrees)
Slack 21	+2.987
60	+3.584
120	+4.372
180	+5.066
240	+5.749
300	+6.401
360	+7.041
420	+7.705
480	+8.477
420	+8.201
360	+7.884
300	+7.505
240	+6.964
180	+6.290
120	+5.420
60	+4.421
Slack 22	+3.525

REMARKS
(Record maximum torque applied, any significant observations)

SLOP

Initial - CW (+2.336)
CCW (-0.624)

Final - CW (+2.725)
CCW (-0.075

Error was made in this measurement. I should have used the torque in place for more accuracy. All Slop.

Initial Angle Reading (Repeatability Setup) +1.611 → 000 Torque

Final Angle Reading (Repeatability Setup) +0.036 → 000 Torque

TABLE 2

Date 7-11,12
Hex Ball Specimen No. 2
Hex Ball Housing Specimen No. 7
Run No. 3

		TRACK CYCLE NO. 1		TRACK CYCLE NO. 2		TRACK CYCLE NO. 3		TRACK CYCLE NO. 4		TRACK CYCLE NO. 5	
Set Point & Direction		Applied Torque	Angle	Applied Torque	Angle	Applied Torque	Angle	Applied Torque	Angle	Applied Torque	Angle
0	0 (CW)	22	-0.076	20	.000	24	-0.075	25	+0.262	25	+0.667
60	5 CW	61	+0.335	60	+0.546	60	+0.509	60	+0.692	60	+1.064
120	10 CW	121	+1.136	120	+1.525	120	+1.687	120	+1.640	120	+1.726
180	15 CW	180	+1.858	180	+2.305	180	+2.479	180	+2.458	180	+2.504
240	20 CW	140	+2.575	240	+3.050	240	+3.236	240	+3.202	240	+3.225
300	25 CW	300	+3.271	300	+3.775	300	+3.925	300	+3.898	300	+3.942
360	30 CW	360	+4.023	360	+4.533	360	+4.606	360	+4.581	360	+4.617
420	35 CW	421/409	+4.745	420	+5.305	420	+5.313	420	+5.330	420	+5.309
360	30 CW	360	+4.50	360	+5.080	360	+5.039	360	+5.079	360	+5.058
300	25 CW	300	+4.250	300	+4.751	300	+4.703	300	+4.757	300	+4.736
240	20 CW	240	+3.876	240	+4.362	240	+4.304	240	+4.368	240	+4.352
180	15 CW	180	+3.381	180	+3.830	180	+3.746	180	+3.818	180	+3.699
120	10 CW	120	+2.698	120	+3.074	120	+2.940	120	+2.990	120	+3.017
60	5 CW	60	+1.762	60	+2.141	60	+1.964	60	+2.001	60	+2.051
0	0 (CW)	23	+0.955	21	+1.278	27	+1.215	25	+1.193	26	+1.252
0	0 (CCW)	16/22	+0.795	18	-2.704	19	-2.703	19	-2.870	19	-2.714
60	5 CCW	-60	-3.60	60	-3.836	60	-3.920	60	-4.088	60	-4.212
120	10 CCW	-120	-4.585	120	-4.862	120	-5.058	120	-5.184	120	-5.330
180	15 CCW	-180	-5.385	180	-5.615	180	-5.896	180	-6.352	180	-6.030
240	20 CCW	-240	-6.230	240	-6.385	240	-6.680	240	-6.690	240	-6.990
300	25 CCW	-300	-7.095	300	-7.260	300	-.6430	300	-7.434	300	-7.710
360	30 CCW	-360	-7.820	360	-7.950	360	-8.150	360	-8.070	360	-8.179
420	35 CCW	-420	-8.730	420	-8.750	420	-8.950	420	-8.850	420	-8.823
360	30 CCW	-360	-8.435	360	-8.490	360	-8.600	360	-8.600	360	-8.675
300	25 CCW	-300	-8.120	300	-8.122	300	-8.280	300	-8.065	300	-8.497
240	20 CCW	-240	-7.665	240	-7.755	240	-7.880	240	-7.818	240	-8.04
180	15 CCW	-180	-6.860	180	-7.110	180	-7.270	180	-7.360	180	-7.462
120	10 CCW	-120	-6.345	120	-6.269	120	-6.310	120	-6.318	120	-6.512
60	5 CCW	-60	-5.400	60	-5.280	60	-5.375	60	-5.553	60	-5.497
0	0 (CCW)	-23	-4.558	19	-4.392	20	-4.537	20	-4.695	20	4.740

TABLE 2 (Continued)

Date 7-16-17
Hex Ball Specimen No. 2
Hex Ball Housing Specimen No. 2
Run No. 3

Set Point & Direction	CYCLE NO. 6 Applied Torque	CYCLE NO. 6 Angle	CYCLE NO. 7 Applied Torque	CYCLE NO. 7 Angle	CYCLE NO. 8 Applied Torque	CYCLE NO. 8 Angle	CYCLE NO. 9 Applied Torque	CYCLE NO. 9 Angle	CYCLE NO. 10 Applied Torque	CYCLE NO. 10 Angle
0 (CW)	26	+0.193	23	-0.980	26	+1.806	25	+0.249	26	-0.363
5 CW	60	+0.618	60	+0.239	60	+2.253	60	+1.664	60	+0.678
10 CW	120	+1.651	120	+1.513	120	+3.004	120	+2.801	120	+1.702
15 CW	180	+2.447	180	+2.317	180	+3.748	180	+3.470	180	+2.422
20 CW	240	+3.195	240	+3.042	240	+4.430	240	+4.153	240	+3.103
25 CW	300	+3.927	300	+3.804	300	+5.091	300	+4.819	300	+3.771
30 CW	360	+4.617	360	+4.469	360	+5.736	360	+5.509	360	+4.455
35 CW	420	+5.299	420	+5.166	420	+6.438	420	+6.146	420	+5.470
30 CW	360	+5.041	360	+4.946	360	+6.153	360	+5.877	360	+5.176
25 CW	300	+4.731	300	+4.638	300	+5.810	300	+5.534	300	+4.832
20 CW	240	+4.348	240	+4.270	240	+5.425	240	+5.138	240	+4.409
15 CW	180	+3.813	180	+3.772	180	+4.940	180	+4.638	180	+3.871
10 CW	120	+3.027	120	+3.013	120	+4.237	120	+3.934	120	+3.095
5 CW	60	+2.058	60	+2.007	60	+3.250	60	+2.934	60	+2.071
0 (CW)	26	+1.290	24	+1.172	26	+2.538	25	+2.158	27	+1.345
0 (CCW)	19	-2.568	23	-2.834	23	-0.902	22	-2.899	24	-3.556
5 CCW	60	-4.740	60	-4.358	60	-2.267	60	-4.262	60	-4.062
10 CCW	120	-5.493	120	-5.508	120	-3.353	120	-5.333	120	-5.015
15 CCW	180	-6.251	180	-6.280	180	-4.128	180	-6.084	180	-5.780
20 CCW	240	-7.051	240	-7.004	240	-4.813	240	-6.783	240	-6.469
25 CCW	300	-7.655	300	-.7681	300	-5.539	300	-7.489	300	-7.186
30 CCW	360	-8.400	360	-8.344	360	-6.216	360	-8.152	360	-7.844
35 CCW	420	-8.978	420	-9.017	420	-6.900	420	-8.822	420	-8.536
30 CCW	360	-8.886	360	-8.721	360	-6.609	360	-8.568	360	-8.262
25 CCW	300	-8.610	300	-8.404	300	-6.252	300	-8.244	300	-6.921
20 CCW	240	-8.127	240	-7.977	240	-5.828	240	-7.820	240	-7.486
15 CCW	180	-7.750	180	-7.471	180	-5.299	180	-7.276	180	-6.951
10 CCW	120	-6.750	120	-6.658	120	-4.49	120	-6.523	120	-6.167
5 CCW	60	-5.840	60	-5.674	60	-3.462	60	-5.509	60	-5.148
0 (CCW)	19	-4.920	24	-4.884	23	-2.674	24	-4.722	23	-4.328

TABLE 2

Date 7/22 - 7/23
Hex Ball Specimen No. 2
Hex Ball Housing Specimen No. 2
Run No. 4

Set Point & Direction	CYCLE NO. 1 Applied Torque	CYCLE NO. 1 Angle	CYCLE NO. 2 Applied Torque	CYCLE NO. 2 Angle	CYCLE NO. 3 Applied Torque	CYCLE NO. 3 Angle	CYCLE NO. 4 Applied Torque	CYCLE NO. 4 Angle	CYCLE NO. 5 Applied Torque	CYCLE NO. 5 Angle
0 (CW)	024	+0.445	024	0.948	024	+1.438	023	+0.168	021	+0.580
5 CW	60	+1.211	60	+1.472	60	+1.952	60	+0.865	60	+1.064
10 CW	120	+2.068	120	+2.285	120	+2.757	120	+1.582	120	+1.881
15 CW	180	+2.804	180	+3.044	180	+3.462	180	+2.257	180	+2.523
20 CW	240	+3.497	240	+4.237	240	+4.117	240	+2.913	240	+3.154
25 CW	300	+4.155	300	+4.560	300	+4.782	300	+3.555	300	+3.812
30 CW	360	+4.836	360	+5.429	360	+5.448	360	+4.213	360	+4.429
35 CW	420	+5.537	420	+6.331	420	+6.264	420	+4.891	420	+5.066
30 CW	360	+5.256	360	+6.056	360	+5.972	360	+4.627	360	+4.800
25 CW	300	+4.908	300	+5.705	300	+5.638	300	+4.296	300	+4.472
20 CW	240	+4.516	240	+5.301	240	+5.222	240	+3.923	240	+4.085
15 CW	180	+3.945	180	+4.712	180	+4.622	180	+3.362	180	+3.546
10 CW	120	+3.119	120	+3.859	120	+3.782	120	+2.592	120	+2.855
5 CW	60	+2.159	60	+2.913	60	+2.800	60	+1.612	60	+1.866
0 (CW)	23	+1.431	25	+2.084	26	+2.050	24	+0.782	23	+1.014
0 (CCW)	23	-4.742	25	-3.826	23	-3.732	23	-4.680	24	-4.916
5 CCW	60	-5.364	60	-4.472	60	-4.407	60	-5.190	60	-5.431
10 CCW	120	-6.236	120	-5.300	120	-5.207	120	-6.015	120	-6.223
15 CCW	180	-6.970	180	-6.031	180	-5.923	180	-6.696	180	-6.981
20 CCW	240	-7.665	240	-6.751	240	-6.620	240	-7.363	240	-7.598
25 CCW	300	-8.377	300	-7.479	300	-7.280	300	-8.009	300	-8.246
30 CCW	360	-9.105	360	-9.253	360	-7.910	260	-8.622	360	-8.878
35 CCW	420	-9.922	420	-10.150	420	-8.599	420	-9.271	420	-9.518
30 CCW	360	-9.644	360	-9.875	360	-8.328	360	-9.003	360	-9.246
25 CCW	300	-9.257	300	-9.526	300	-7.981	300	-8.671	300	-8.923
20 CCW	240	-8.864	240	-9.100	240	-7.580	240	-8.274	240	-8.523
15 CCW	180	-8.282	180	-8.468	180	-7.005	180	-7.724	180	-7.978
10 CCW	120	-7.459	120	-7.680	120	-6.226	120	-7.000	120	-7.254
5 CCW	60	-6.431	60	-6.697	60	-5.230	60	-5.974	60	-6.281
0 (CCW)	24	-5.586	24	-5.813	24	-4.379	25	-5.136	24	-5.381

TABLE 2 (Continued)

Date 7/24
Hex Ball Specimen No. 2
Hex Ball Housing Specimen No. 2
Run No. 4

	CYCLE NO. 6		CYCLE NO. 7		CYCLE NO. 8		CYCLE NO. 9		CYCLE NO. 10	
Set Point & Direction	Applied Torque	Angle	Applied Torque	Angle	Applied Torque	Angle	Applied Torque	Angle	Applied Torque	Angle
0 (CW)	025	+1.182	23	+0.655	22	+3.616	24	+3.838	25	+4.096
5 CW	60	+1.575	60	+1.035	60	+4.188	60	+4.136	60	+4.761
10 CW	120	+2.334	120	+1.824	120	+4.915	120	+4.836	120	+5.894
15 CW	180	+3.018	180	+2.521	180	+5.592	180	+5.522	180	+6.606
20 CW	240	+3.655	240	+3.175	240	+6.259	240	+6.201	240	+7.438
25 CW	300	+4.222	300	+3.805	300	+6.915	300	+6.785	300	+8.024
30 CW	360	+4.800	360	+4.451	360	7.572	360	+7.417	360	+8.662
35 CW	420	+5.414	420	+5.096	420	+8.217	420	+8.050	420	+9.308
30 CW	360	+5.153	360	+4.824	360	+7.960	360	+7.796	360	+9.015
25 CW	300	+4.838	300	+4.520	300	+7.648	300	+7.451	300	+8.985
20 CW	240	+4.459	240	+4.134	240	+7.269	240	+7.103	240	+8.921
15 CW	180	+3.933	180	+3.600	180	+6.753	180	+6.571	180	+8.295
10 CW	120	+3.272	120	+2.383	120	+6.042	120	+5.921	120	+8.207
5 CW	60	+2.305	60	+1.972	60	+5.129	60	+5.032	60	+7.355
0 (CW)	25	+1.505	24	+1.110	23	+4.238	24	+4.253	24	+6.235
0 (CCW)	22	-4.455	24	-4.409	24	-1.740	23	-1.664	22	-1.135
5 CCW	60	-5.057	60	-4.944	60	-2.157	60	-2.153	60	-1.666
10 CCW	120	-5.814	120	-5.690	120	-2.943	120	-2.882	120	-2.420
15 CCW	180	-6.529	180	-6.390	180	-3.667	180	-3.579	180	-3.117
20 CCW	240	-7.185	240	-7.054	240	-4.327	240	-4.229	240	-3.810
25 CCW	300	-7.829	300	-7.682	300	-4.965	300	-4.841	300	-4.455
30 CCW	360	-8.477	360	-8.308	360	-5.596	360	-5.451	360	-5.063
35 CCW	420	-9.150	420	-8.949	420	-6.269	420	-6.119	420	-5.709
30 CCW	360	-8.878	360	-8.663	360	-5,986	360	-5.866	360	-5.457
25 CCW	300	-8.523	300	-8.315	300	-5.645	300	-5.519	300	-5.113
20 CCW	240	-8.138	240	-7.913	240	-5.228	240	-5.100	240	-4.716
15 CCW	180	-7.600	180	-7.377	180	-4.734	180	-4.640	180	-4.200
10 CCW	120	-6.906	120	-6.695	120	-4.048	120	-4.022	120	-3.565
5 CCW	60	-5.942	60	-5.759	60	-3.178	60	-3.177	60	-2.711
0 (CCW)	24	-5.023	23	-4.824	24	-2.371	23	-2.254	23	-1.793

TABLE 2

Date 7/25-26
Hex Ball Specimen No. 2
Hex Ball Housing Specimen No. 2
Run No. 5

Set Point & Direction	CYCLE NO. 1 Applied Torque	CYCLE NO. 1 Angle	CYCLE NO. 2 Applied Torque	CYCLE NO. 2 Angle	CYCLE NO. 3 Applied Torque	CYCLE NO. 3 Angle	CYCLE NO. 4 Applied Torque	CYCLE NO. 4 Angle	CYCLE NO. 5 Applied Torque	CYCLE NO. 5 Angle
0 (CW)	23	+5.786	24	+5.258	26	+4.465	025	3.385	026	+3.768
5 CW	60	+6.317	60	+5.610	60	+4.998	60	+3.784	60	+4.116
10 CW	120	+7.028	120	+6.334	120	+5.737	120	+4.529	120	+4.822
15 CW	180	+7.707	180	+7.020	180	+6.409	180	+5.205	180	+5.479
20 CW	240	+8.287	240	+7.667	240	+7.306	240	+5.856	240	+6.121
25 CW	300	+8.933	300	+8.295	300	+7.681	300	+6.498	300	+6.759
30 CW	360	+9.585	360	+8.934	360	+8.276	360	+7.196	360	+7.361
35 CW	420	+10.207	420	+9.558	420	+8.899	420	+7.863	420	+7.968
30 CW	360	+9.933	360	+9.306	360	+8.613	360	+7.607	360	+7.719
25 CW	300	+9.601	300	+8.986	300	+8.325	300	+7.283	300	+7.403
20 CW	240	+9.189	240	+8.601	240	+7.933	240	+6.898	240	+7.041
15 CW	180	+8.577	180	+8.099	180	+7.409	180	+6.416	180	+6.581
10 CW	120	+7.894	120	+7.359	120	+6.713	120	+5.706	120	+5.898
5 CW	60	+6.893	60	+6.393	60	+5.722	60	+4.732	60	+5.003
0 (CW)	24	+6.076	26	+5.528	25	+4.926	26	+3.904	26	+4.153
0 (CCW)	23	-1.305	21	-1.858	24	-1.232	24	-2.226	25	-2.231
5 CCW	60	-1.974	60	-2.276	60	-1.777	60	-3.310	60	-2.820
10 CCW	120	-2.789	120	-3.036	120	-2.582	120	-3.710	120	-3.505
15 CCW	180	-3.670	180	-3.751	180	-3.314	180	-4.226	180	-4.220
20 CCW	240	-4.259	240	-4.472	240	-4.002	240	-4.857	240	-4.874
25 CCW	300	-5.009	300	-5.120	300	-4.645	300	-5.477	300	-5.426
30 CCW	360	-5.609	360	-5.786	360	-5.334	360	-6.022	360	-5.966
35 CCW	420	-6.305	420	-6.473	420	-5.945	420	-6.581	420	-6.511
30 CCW	360	-6.031	360	-6.189	360	-5.684	360	-6.321	360	-6.278
25 CCW	300	-5.689	300	-5.844	300	-5.354	300	-6.054	300	-5.998
20 CCW	240	-5.279	240	-5.403	240	-4.923	240	-5.712	240	-5.640
15 CCW	180	-4.675	180	-4.844	180	-4.372	180	-5.274	180	-5.188
10 CCW	120	-3.917	120	-4.088	120	-3.662	120	-4.620	120	-4.569
5 CCW	60	-2.878	60	-3.046	60	-2.716	60	-3.721	60	-3.666
0 (CCW)	24	-2.041	22	-2.147	23	-1.786	25	-2.816	24	-2.811

TABLE 2 (Continued)

Date 7/29
Hex Ball Specimen No. 2
Hex Ball Housing Specimen No. 2
Run No. 5

Set Point & Direction	CYCLE NO. 6 Applied Torque	CYCLE NO. 6 Angle	CYCLE NO. 7 Applied Torque	CYCLE NO. 7 Angle	CYCLE NO. 8 Applied Torque	CYCLE NO. 8 Angle	CYCLE NO. 9 Applied Torque	CYCLE NO. 9 Angle	CYCLE NO. 10 Applied Torque	CYCLE NO. 10 Angle
0 (CW)	25	+3.819	25	+3.635	19	+3.585	19	+3.624	19	+3.161
5 CW	60	+4.317	60	+4.138	60	+3.980	60	+4.016	60	+3.736
10 CW	120	+5.054	120	+4.874	120	+4.597	120	+4.677	120	+4.517
15 CW	180	+5.699	180	+5.568	180	+5.300	180	+5.327	180	+5.235
20 CW	240	+6.366	240	+6.165	240	+5.993	240	+6.004	240	+5,952
25 CW	300	+6.981	300	+6.828	300	+6.667	300	+6.734	300	+6.672
30 CW	360	+7.590	360	+7.433	360	+7.311	360	+7.378	260	+7.375
35 CW	420	+8.205	420	+8.078	420	+7.990	420	+8.067	420	+8.076
30 CW	360	+7.924	360	+7.807	360	+7.736	360	+7.809	360	+7.811
25 CW	300	+7.635	300	+7.493	300	+7.414	300	+7.482	300	+7.485
20 CW	240	+7.272	240	+7.121	240	+7.056	240	+7.114	240	+7.104
15 CW	180	+6.827	180	+6.666	180	+6.606	180	+6.663	180	+6.659
10 CW	120	+6.168	120	+6.009	120	+5.998	120	+6.053	120	+6.075
5 CW	60	+5.270	60	+5.107	60	+5.182	60	+5.256	60	+5.287
0 (CW)	24	+4.475	25	+4.290	19	+4.265	19	+4.274	20	+4.381
0 (CCW)	22	-1.907	*		18	-2.439	18	-2.589	18	-2.910
5 CCW	60	-2.298	60	-3.051	60	-3.015			60	-3.284
10 CCW	120	-3.081	120	-3.834	120	-3.847			120	-3.888
15 CCW	180	-3.781	180	-4.536	180	-4.618			180	-4.602
20 CCW	240	-4.412	240	-5.208	240	-5.336			240	-5.323
25 CCW	300	-4.989	300	-5.868	300	-6.016			300	-6.061
30 CCW	360	-5.531	360	-6.568	360	-6.715	360	-6.780	360	-6.821
35 CCW	420	-6.073	420	-6.427	420	-7.455	420	-7.516	420	-7.550
30 CCW	360	-5.847	360	-7.160	360	-7.180	360	-7.223	360	-7.260
25 CCW	300	-5.557	300	-6.814	300	-6.839			300	-6.925
20 CCW	240	-5.212	240	-6.424	240	-6.442			240	-6.529
15 CCW	180	-4.760	180	-5.927	180	-5.981			180	-6.081
10 CCW	120	-4.141	120	-5.208	120	-5.351			120	-5.505
5 CCW	60	-3.246	60	-4.342	60	-4.514			60	-4.761
0 (CCW)	23	-2.323	19	-2.789	18	3.517	18	-3.651	18	-3.591

TABLE 2

Date 7/30
Hex Ball Specimen No. 2
Hex Ball Housing Specimen No. 2
Run No. 6

Set Point & Direction	CYCLE NO. 1 Applied Torque	CYCLE NO. 1 Angle	CYCLE NO. 2 Applied Torque	CYCLE NO. 2 Angle	CYCLE NO. 3 Applied Torque	CYCLE NO. 3 Angle	CYCLE NO. 4 Applied Torque	CYCLE NO. 4 Angle	CYCLE NO. 5 Applied Torque	CYCLE NO. 5 Angle
0 (CW)	17	+3.041	18	+2.995	18	+3.008	18	+3.004	18	+3.003
5 CW	60	+3.829							60	+4.215
10 CW	120	+4.581							120	+4.628
15 CW	180	+5.304							180	+5.285
20 CW	240	+6.023							240	+5.968
25 CW	300	+6.773							300	+6.771
30 CW	360	+7.545	360	+7.543	360	+7.592	360	+7.593	360	+7.575
35 CW	420	+8.221	420	+8.226	420	+8,286	420	+8.230	420	+8.240
30 CW	360	+7.965	360	+7.957	360	+8.008	360	+7.963	360	+7.963
25 CW	300	+7.623							300	+7.634
20 CW	240	+7.255							240	+7.261
15 CW	180	6.740							180	+6.258
10 CW	120	+6.033							120	6.160
5 CW	60	+5.149							60	+5.307
0 (CW)	20	+4.237	19	+4.269	19	+4.222	19	+4.095	19	+4.440
0 (CCW)	18	-2.418	18	-2.369	18	-2.860	18	-2.776	18	-2.579
5 CCW	60	-3.034							60	-3.024
10 CCW	120	-3.913							120	-3.872
15 CCW	180	-4.741							180	-4.662
20 CCW	240	-5.505							240	-5.398
25 CCW	300	-6.363							300	-6.289
30 CCW	360	-7.114	360	-7.116	360	-7.106	360	-7.084	360	-7.080
35 CCW	420	-7.860	420	-7.828	420	-7.831	420	-7.770	420	-7.737
30 CCW	360	-6.588	360	-7.536	360	-7.533	360	-7.475	360	-7.447
25 CCW	300	-7.237							300	-7.115
20 CCW	240	-6.839							240	-6.728
15 CCW	180	-6.279							180	-6.230
10 CCW	120	-5.553							120	-5.655
5 CCW	60	-4.622							60	-4.945
0 (CCW)	18	-3.558	18	-3.657	18	-3.790	18	-3.901	18	-3.917

TABLE 2 (Continued)

Date 7/31-8/1
Hex Ball Specimen No. 2
Hex Ball Housing Specimen No. 2
Run No. 6

Set Point & Direction	CYCLE NO. 6 Applied Torque	CYCLE NO. 6 Angle	CYCLE NO. 7 Applied Torque	CYCLE NO. 7 Angle	CYCLE NO. 8 Applied Torque	CYCLE NO. 8 Angle	CYCLE NO. 9 Applied Torque	CYCLE NO. 9 Angle	CYCLE NO. 10 Applied Torque	CYCLE NO. 10 Angle
0 (CW)	18	+3.003	18	+5.015	18	+2.977	18	+3.989	18	+3.015
5 CW									60	+4.243
10 CW									120	+4.626
15 CW									180	+5.355
20 CW									240	+6.014
25 CW									300	6.789
30 CW	360	+7.602	360	+7.589	360	+7.567	360	+7.550	360	+7.603
35 CW	420	+8.259	420	+8.322	420	+8.230	420	+8.230	420	+8.252
30 CW	360	+7.989	360	+8.033	360	+7.963	360	+7.928	360	+7.984
25 CW									300	+7.652
20 CW									240	+7.270
15 CW									180	+6.815
10 CW									120	+6.216
5 CW									60	+5.501
0 (CW)	19	+4.457	19	+4.548	17	+4.099	19	+4.564	19	+4.654
0 (CCW)	18	-2.948	18	-2.398	18	-2.390	18		18	-2.461
5 CCW									60	-2.956
10 CCW									120	-3.863
15 CCW									180	-4.638
20 CCW									240	-5.342
25 CCW									300	-6.278
30 CCW	360	-7.065	360	-7.016	360	-6.978	360	-6.989	360	-6.959
35 CCW	420	-7.737	420	-7.676	420	-7.643	420	-7.613	420	-7.604
30 CCW	360	-7.453	360	-7.390	360	-7.370	360	-7.332	360	-7.324
25 CCW									300	-6.986
20 CCW									240	-6.607
15 CCW									180	-6.134
10 CCW									120	-5.573
5 CCW									60	-4.887
0 (CCW)	18	-3.844	18	-4.116	18	-4.113	18	-4.006	18	-4.102

TABLE 2

Date 8/1-2
Hex Ball Specimen No. 2
Hex Ball Housing Specimen No. 2
Run No. 7

Set Point & Direction	CYCLE NO. 1 Applied Torque	CYCLE NO. 1 Angle	CYCLE NO. 2 Applied Torque	CYCLE NO. 2 Angle	CYCLE NO. 3 Applied Torque	CYCLE NO. 3 Angle	CYCLE NO. 4 Applied Torque	CYCLE NO. 4 Angle	CYCLE NO. 5 Applied Torque	CYCLE NO. 5 Angle
0 (CW)	17	+2.936	18	+3.011	18	+3.059	18	+3.070	18	+3.062
5 CW	60	+4.180							60	+3.774
10 CW	120	+4.671							120	+4.651
15 CW	180	+5.431							180	+5.448
20 CW	240	+6.232							240	+6.143
25 CW	300	+7.028							300	+6.895
30 CW	360	+7.791	360	+7.774	360	+7.759	360	+7.773	360	+7.694
35 CW	420	+8.460	420	+8.486	420	+8.489	420	+8.514	420	+8.500
30 CW	360	+8.200	360	+8.231	360	+8.211	360	+8.236	360	+8.226
25 CW	300	+7.846							300	+7.884
20 CW	240	+7.479							240	+7.512
15 CW	180	+6.902							180	+7.013
10 CW	120	6.206							120	6.382
5 CW	60	5.372							60	5.582
0 (CW)	19	4.396	19	+4.503	19	+4.520	19	+4.594	19	+4.542
0 (CCW)	18	-2.698	18	-2.481	18	-2.420	18	-3.446	18	-2.558
5 CCW	60	-3.155							60	-3.006
10 CCW	120	-3.944							120	-3.815
15 CCW	180	-4.720							180	-4.587
20 CCW	240	-5.519							240	-5.370
25 CCW	300	-6.576							300	-6.329
30 CCW	360	-7.281	360	-7.188	360	-7.181	360	-7.097	360	-7.034
35 CCW	420	-7.930	420	-6.865	420	-6.825	420	-7.788	420	-7.686
30 CCW	360	-7.646	360	-7.578	360	-7.532	360	-7.491	360	-7.410
25 CCW	300	-7.298							300	-7.050
20 CCW	240	-6.866							240	-6.663
15 CCW	180	-6.312							180	-6.143
10 CCW	120	-5.588							120	-5.572
5 CCW	60	-4.670							60	-4.874
0 (CCW)	18	-3.498	18	-3.665	18	-3.782	18	-3.862	18	-3.905

TABLE 2 (Continued)

Date 8/5
Hex Ball Specimen No. 2
Hex Ball Housing Specimen No. 2
Run No. 7

Set Point & Direction	CYCLE NO. 6 Applied Torque	CYCLE NO. 6 Angle	CYCLE NO. 7 Applied Torque	CYCLE NO. 7 Angle	CYCLE NO. 8 Applied Torque	CYCLE NO. 8 Angle	CYCLE NO. 9 Applied Torque	CYCLE NO. 9 Angle	CYCLE NO. 10 Applied Torque	CYCLE NO. 10 Angle
0 (CW)	19	+3.040	19	3.026	18	+3.122	19	+3.078	19	+3.210
5 CW									60	+4.306
10 CW									120	+4.734
15 CW									180	5.477
20 CW									240	+6.344
25 CW									300	+7.156
30 CW	360	+7.959	360	+7.981	360	+8.006	360	+8.011	360	+7.923
35 CW	420	+8.620	420	+8.633	420	+8.652	420	+8.676	420	+8.656
30 CW	360	+8.347	360	+8.336	360	+8.368	360	+8.387	360	+8.345
25 CW									300	+8.046
20 CW									240	+7.668
15 CW									180	+7.163
10 CW									120	+6.582
5 CW									60	+5.812
0 (CW)	19	+4.755	19	+4.764	19	+4.103	19	+4.852	19	+4.936
0 (CCW)	18	-2.309	18	-2.255	18	-2.370	18	-2.772	18	-2.403
5 CCW									60	-2.844
10 CCW									120	-3.673
15 CCW									180	-4.482
20 CCW									240	-5.596
25 CCW									300	-6.354
30 CCW	360	-7.128	360	-7.080	360	-7.045	360	-7.027	360	-6.988
35 CCW	420	-7.799	420	-7.733	420	-7.661	420	-7.699	420	-7.631
30 CCW	360	-7.513	360	-7.447	360	-7.385	360	-7.394	360	-7.353
25 CCW									300	-7.007
20 CCW									240	-6.597
15 CCW									180	-6.091
10 CCW									120	-5.528
5 CCW									60	-4.869
0 (CCW)	18	-3.896	18	-3.994	18	-4.028	18	-4.011	18	-3.990

TABLE 1

Date 8/6
Hex Ball Specimen No. 3
Hex Ball Housing Specimen No. 3
Run No. 8
Direction of Torque Application

TORQUE (in-lb)	ANGLE (Degrees)	REMARKS (Record maximum torque applied, any significant observations)
19	+1.550	
60	+2.999	
120	+3.545	
180	+4.370	
240	+5.286	
300	+6.190	
360	+7.171	
420	+8.021	MAX TORQUE 35 ft-lb
360	+7.772	
300	+7.420	
240	+6.994	
180	+6.435	
120	+5.645	
60	+4.625	
Slack 20	3.732	
		I have no explanation for this error.

Initial Angle Reading (Repeatability Setup) +1.550

Final Angle Reading (Repeatability Setup) +3.732

TABLE 1

Date 8/6
Hex Ball Specimen No. 3
Hex Ball Housing Specimen No. 3
Run No. 9
Direction of Torque Application

TORQUE (in-lb)	ANGLE (Degrees)	REMARKS (Record maximum torque applied, any significant observations)
19	+3.346	
60	+4.030	
120	+4.842	
180	+5.564	
240	+6.227	
300	+6.876	
360	+7.483	
420	8.141	
480	+9.029	MAX TORQUE 40 ft-lb
420	+8.725	
360	+8.484	
300	+8.086	
240	+7.584	
180	+6.919	
120	+6.040	
60	+5.033	
19	+4.074	

Initial Angle Reading (Repeatability Setup) 3.346

Final Angle Reading (Repeatability Setup) 4.074

TABLE 2

Date 8/7
Hex Ball Specimen No. 4
Hex Ball Housing Specimen No. 4
Run No. 10

Set Point & Direction	CYCLE NO. 1 Applied Torque	CYCLE NO. 1 Angle	CYCLE NO. 2 Applied Torque	CYCLE NO. 2 Angle	CYCLE NO. 3 Applied Torque	CYCLE NO. 3 Angle	CYCLE NO. 4 Applied Torque	CYCLE NO. 4 Angle	CYCLE NO. 5 Applied Torque	CYCLE NO. 5 Angle
0 (CW)	18	+4.014	18	+2.079	18	+2.186	17	+2.249	18	+2.551
5 CW	60	+4.662	60	+2.915	60	+3.027	60	+3.232		
10 CW	120	5.465	120	+3.777	120	+4.014	120	+4.122		
15 CW	180	+6.238	180	+4.732	180	+5.168	180	+5.404		
20 CW	240	+7.009	240	+6.174	240	+6.390	240	+6.567		
25 CW	300	+7.735	300	+7.314	300	+7.383	300	+7.895		
30 CW	360	+8.501	360	+8.100	360	+8.142	360	+8.836	360	+8.822
35 CW	420	+9.241	420	+8.954	420	+8.954	420	+9.616	420	+9.661
30 CW	360	+8.971	360	+8.699	360	+8.690	360	+9.402	360	+9.443
25 CW	300	+9.614	300	+8.347	300	+8.325	300	+9.053		
20 CW	240	+8.158	240	+7.848	240	+7.828	240	+8.556		
15 CW	180	+7.536	180	+7.207	180	+7.174	180	+7.905		
10 CW	120	+6.690	120	+6.360	120	+6.334	120	+6.979		
5 CW	60	+5.703	60	+5.394	60	+5.328	60	+5.987		
0 (CW)	18	+4.825	20	+4.610	20	+4.490	19	+5.295	19	+5.336
0 (CCW)	18	-1.207	18	-1.182	18	-1.394	18	-0.975	18	-0.893
5 CCW	60	-1.804	60	-1.706	60	-1.967	60	-1.567		
10 CCW	120	-2.545	120	-3.224	120	-3.014	120	-2.413		
15 CCW	180	-3.880	180	-4.274	180	-4.443	180	-4.460		
20 CCW	240	-4.741	240	-5.108	240	-5.376	240	-5.348		
25 CCW	300	-5.570	300	-5.978	300	-6.251	300	-6.134		
30 CCW	360	-6.587	360	-6.903	360	-7.047	360	-6.878	360	-6.855
35 CCW	420	-7.683	420	-7.708	420	-7.925	420	-7.686	420	-7.601
30 CCW	360	-7.483	360	-7.475	360	-7.654	360	-7.424	360	-7.270
25 CCW	300	-7.080	300	-7.116	300	-7.729	300	-7.061		
20 CCW	240	-6.591	240	-6.566	240	-6.716	240	-6.505		
15 CCW	180	-5.896	180	-5.905	180	-5.988	180	-5.799		
10 CCW	120	-4.991	120	-5.048	120	-5.115	120	-4.933		
5 CCW	60	-3.960	60	-4.050	60	-4.116	60	-3.972		
0 (CCW)	18	-3.009	18	-3.197	18	-3.140	18	-3.064	18	-2.911

TABLE 2 (Continued)

Date 8/8
Hex Ball Specimen No. 4
Hex Ball Housing Specimen No. 4
Run No. 10

Set Point & Direction	CYCLE NO. 6 Applied Torque	CYCLE NO. 6 Angle	CYCLE NO. 7 Applied Torque	CYCLE NO. 7 Angle	CYCLE NO. 8 Applied Torque	CYCLE NO. 8 Angle	CYCLE NO. 9 Applied Torque	CYCLE NO. 9 Angle	CYCLE NO. 10 Applied Torque	CYCLE NO. 10 Angle
0 (CW)	18	+2.686	18	+2.669	18	+2.765	18	+2.769	18	+2.759
5 CW									60	+4.444
10 CW									120	+5.251
15 CW									180	+6.252
20 CW									240	+7.105
25 CW									300	+7.925
30 CW	360	+8.863	360	+8.781	360	+8.733	360	+8.706	360	+8.674
35 CW	420	+9.650	420	+9.582	420	+9.536	420	+9.503	420	+9.394
30 CW	360	+9.430	360	+9.352	360	+9.295	360	+9.264	360	+9.162
25 CW									300	+8.808
20 CW									240	+8.289
15 CW									180	+7.634
10 CW									120	+6.799
5 CW									60	+5.820
0 (CW)	19	+5.262	19	+5.124	19	+5.113	19	+5.030		+5.011
0 (CCW)	18	-1.212	18	-1.313	18	-1.247	18	-1.488	18	-1.985
5 CCW									60	-2.565
10 CCW									120	-3.509
15 CCW									180	-4.517
20 CCW									240	-5.406
25 CCW									300	-6.186
30 CCW	360	-6.905	360	-6.895	360	-6.874	360	-6.827	360	-6.835
35 CCW	420	-7.593	420	-7.589	420	-7.594	420	-7.579	420	-7.570
30 CCW	360	-7.330	360	-7.333	360	-7.337	370	-7.307	360	-7.311
25 CCW									300	-6.940
20 CCW									240	-6.378
15 CCW									180	-5.667
10 CCW									120	-4.828
5 CCW									60	-3.852
0 (CCW)	18	-2.952	18	-2.930	18	-2.925	18	-2.759	18	-2.905

TABLE 2

Date 8/9
Hex Ball Specimen No. 4
Hex Ball Housing Specimen No. 4
Run No. 11

Set Point & Direction	CYCLE NO. 1 Applied Torque	CYCLE NO. 1 Angle	CYCLE NO. 2 Applied Torque	CYCLE NO. 2 Angle	CYCLE NO. 3 Applied Torque	CYCLE NO. 3 Angle	CYCLE NO. 4 Applied Torque	CYCLE NO. 4 Angle	CYCLE NO. 5 Applied Torque	CYCLE NO. 5 Angle
0 (CW)	19	+2.702	18	+2.798	19	+2.783	19	+2.854	19	+2.902
5 CW	60	+4.474							60	+4.667
10 CW	120	+5.270							120	+5.378
15 CW	180	+6.264							180	+6.373
20 CW	240	+7.082							240	+7.186
25 CW	300	+7.899							300	+7.927
30 CW	360	+8.678	360	+8.684	360	+8.706	360	+8.675	360	+8.737
35 CW	420	+9.503	420	+9.436	420	+9.455	420	+9.398	420	+9.363
30 CW	360	+9.230	360	+9.187	360	+9.191	360	+9.154	360	+9.117
25 CW	300	+8.882							300	+8.757
20 CW	240	8.531							240	+8.223
15 CW	180	+7.697							180	+7.560
10 CW	120	+6.854							120	+6.749
5 CW	60	+5.870							60	+5.781
0 (CW)	20	+5.057	20	+4.950	20	+4.980	20	+4.962	20	+4.972
0 (CCW)	18	-0.875	18	-1.902	18	-1.298	18	-1.958	18	-1.688
5 CCW	60	-1.504							60	-2.275
10 CCW	120	-3.475							120	-3.677
15 CCW	180	-4.522							180	-4.657
20 CCW	240	-5.404							240	-5.476
25 CCW	300	-6.167							300	-6.255
30 CCW	360	-6.930	360	-6.936	360	-6.935	360	-7.389	360	-6.950
35 CCW	420	-7.635	420	-7.680	420	-7.569	420	-7.723	420	-7.673
30 CCW	360	-7.373	360	-7.409	360	-7.429	360	-7.430	360	-7.402
25 CCW	300	-6.995							300	-7.021
20 CCW	240	-6.402							240	-6.414
15 CCW	180	-5.688							180	-5.712
10 CCW	120	-4.813							120	-4.851
5 CCW	60	-3.849							60	-3.867
0 (CCW)	18	-2.924	18	-2.965	18	-2.978	18	-2.980	18	-2.956

TABLE 2 (Continued)

Date 8/12
Hex Ball Specimen No. 4
Hex Ball Housing Specimen No. 4
Run No. 11

Set Point & Direction	CYCLE NO. 6 Applied Torque	CYCLE NO. 6 Angle	CYCLE NO. 7 Applied Torque	CYCLE NO. 7 Angle	CYCLE NO. 8 Applied Torque	CYCLE NO. 8 Angle	CYCLE NO. 9 Applied Torque	CYCLE NO. 9 Angle	CYCLE NO. 10 Applied Torque	CYCLE NO. 10 Angle
0 (CW)	19	+2.927	19	+2.906	19	+2.818	19	+3.023	19	+3.026
5 CW									60	+4.598
10 CW									120	+5.410
15 CW									180	+6.313
20 CW									240	+7.143
25 CW									300	+7.937
30 CW	360	+8.645	360	+8.663	360	+8.638	360	+8.658	360	+8.650
35 CW	420	+9.396	420	+9.414	420	+9.339	420	+9.356	420	+9.360
30 CW	360	+9.140	360	+9.160	360	+9.106	360	+8.999	360	+9.094
25 CW									300	+8.749
20 CW									240	+8.205
15 CW									180	+7.448
10 CW									120	+6.742
5 CW									60	+5.784
0 (CW)	20	+4.958	20	+4.956	20	+4.959	20	+4.927	20	+4.969
0 (CCW)	18	-2.068	18	-2.053	18	-1.553	18	-2.124	18	-2.236
5 CCW									60	-2.802
10 CCW									120	-3.739
15 CCW									180	-4.774
20 CCW									240	-5.522
25 CCW									300	-6.308
30 CCW	360	-6.965	360	-7.027	360	-6.989	360	-6.973	360	-7.001
35 CCW	420	-7.689	420	-7.747	420	-7.656	420	-7.659	420	-7.707
30 CCW	360	-7.402	360	-7.440	360	-7.386	360	-7.377	360	-7.479
25 CCW									300	-7.084
20 CCW									240	-6.491
15 CCW									180	-5.790
10 CCW									120	-4.935
5 CCW									60	-3.964
0 (CCW)	18	-2.986	18	-3.052	18	-2.997	18	-3.003	18	-3.040

TABLE 2

Date 8/13
Hex Ball Specimen No. 4
Hex Ball Housing Specimen No. 4
Run No. 12

Set Point & Direction	CYCLE NO. 1 Applied Torque	CYCLE NO. 1 Angle	CYCLE NO. 2 Applied Torque	CYCLE NO. 2 Angle	CYCLE NO. 3 Applied Torque	CYCLE NO. 3 Angle	CYCLE NO. 4 Applied Torque	CYCLE NO. 4 Angle	CYCLE NO. 5 Applied Torque	CYCLE NO. 5 Angle
0 (CW)	19	+2.831	19	+2.896	19	+2.883	19	+2.960	19	+2.915
5 CW	60	+4.743							60	+4.540
10 CW	120	+5.390							120	+5.476
15 CW	180	+6.293							180	+6.323
20 CW	240	+7.190							240	+7.143
25 CW	300	+7.960							300	+7.954
30 CW	360	+8.639	360	+8.679	360	+8.654	360	+8.661	360	+8.731
35 CW	420	+9.358	420	+9.375	420	+9.347	420	+9.341	420	+9.374
30 CW	360	+9.112	360	+9.142	360	+9.106	360	+9.086	360	+9.129
25 CW	300	+8.725							300	+8.758
20 CW	240	+8.218							240	+8.215
15 CW	180	+7.587							180	+7.573
10 CW	120	+6.788							120	+6.795
5 CW	60	+5.801							60	+5.781
0 (CW)	20	+4.874	20	+4.970	19	+4.922	20	+4.945	20	+4.968
0 (CCW)	18	-2.130	18	-1.540	18	-1.271	18	-1.160	18	-2.193
5 CCW	60	-2.757							60	-2.802
10 CCW	120	-3.736							120	-3.891
15 CCW	180	-4.788							180	-4.784
20 CCW	240	-5.512							240	-5.599
25 CCW	300	-6.311							300	-6.339
30 CCW	360	-6.999	360	-7.054	360	-7.043	360	-7.020	360	-7.047
35 CCW	420	-7.721	420	-7.767	420	-7.754	420	-7.728	420	-7.735
30 CCW	360	-7.444	360	-7.506	360	-7.489	360	-7.468	360	-7.462
25 CCW	300	-7.063							300	-7.092
20 CCW	240	-6.472							240	-6.498
15 CCW	180	-5.773							180	-5.800
10 CCW	120	-4.904							120	-4.951
5 CCW	60	-3.939							60	-3.980
0 (CCW)	18	-2.996	18	-3.076	18	-3.067	18	-3.016	18	-3.028

TABLE 2 (Continued)

Date 8/14
Hex Ball Specimen No. 4
Hex Ball Housing Specimen No. 4
Run No. 12

Set Point & Direction	CYCLE NO. 6 Applied Torque	CYCLE NO. 6 Angle	CYCLE NO. 7 Applied Torque	CYCLE NO. 7 Angle	CYCLE NO. 8 Applied Torque	CYCLE NO. 8 Angle	CYCLE NO. 9 Applied Torque	CYCLE NO. 9 Angle	CYCLE NO. 10 Applied Torque	CYCLE NO. 10 Angle
0 (CW)	19	+2.910	19	+2.920	19	+2.970	19	+2.995	19	+3.091
5 CW									60	+4.661
10 CW									120	+5.415
15 CW									180	+6.330
20 CW									240	+7.126
25 CW									300	+7.883
30 CW	360	+8.688	360	+8.610	360	+8.630	360	+8.665	360	+8.603
35 CW	420	+9.296	420	+9.298	420	+9.325	420	+9.332	420	+9.319
30 CW	360	+9.052	360	+0.053	360	+9.045	360	+9.090	360	+9.073
25 CW									300	+8.723
20 CW									240	+8.182
15 CW									180	+7.540
10 CW									120	+6.741
5 CW									60	+5.741
0 (CW)	20	+4.872	20	+4.947	20	+4.928	20	+4.950	20	4.942
0 (CCW)	18	-2.209	18	-1.504	18	-1.437	18	-1.690	18	-2.282
5 CCW									60	-2.890
10 CCW									120	-3.940
15 CCW									180	-4.836
20 CCW									240	-5.612
25 CCW									300	-6.416
30 CCW	360	-7.776	360	-7.078	360	-7.074	360	-7.708	360	-7.048
35 CCW	420	-7.780	420	-7.799	420	-7.751	420	-7.763	420	-7.745
30 CCW	360	-7.552	360	-7.468	360	-7.467	360	-7.493	360	-7.482
25 CCW									300	-7.101
20 CCW									240	-6.482
15 CCW									180	-5.786
10 CCW									120	-4.973
5 CCW									60	-4.983
0 (CCW)	18	-3.082	18	-3.029	18	-3.106	18	-3.080	18	-3.050

TABLE 2

Date 8/14

Hex Ball Specimen No. 4

Hex Ball Housing Specimen No. 4

Run No. 13

Set Point & Direction	CYCLE NO. 1 Applied Torque	CYCLE NO. 1 Angle	CYCLE NO. 2 Applied Torque	CYCLE NO. 2 Angle	CYCLE NO. 3 Applied Torque	CYCLE NO. 3 Angle	CYCLE NO. 4 Applied Torque	CYCLE NO. 4 Angle	CYCLE NO. 5 Applied Torque	CYCLE NO. 5 Angle
0 (CW)	19	+3.034	19	+3.019	19	+3.050	19	+3.011	19	+3.131
5 CW	60	+4.704							60	+4.635
10 CW	120	+5.456							120	+5.532
15 CW	180	+6.322							180	+6.401
20 CW	240	+7.150							240	+7.189
25 CW	300	+7.938							300	+7.927
30 CW	360	+8.630	360	+8.685	360	+8.678	360	+8.698	360	+8.685
35 CW	420	+9.355	420	+9.392	420	+9.358	420	+9.393	420	+9.406
30 CW	360	+9.130	360	+9.128	360	+9.119	360	+9.153	360	+9.161
25 CW	300	+8.752							300	+8.783
20 CW	240	+8.194							240	+8.229
15 CW	180	+7.551							180	+7.588
10 CW	120	+6.801							120	+6.809
5 CW	60	+5.826							60	+5.850
0 (CW)	20	+4.979	20	+4.977	20	+4.864	20	+4.984	20	+4.993
0 (CCW)	18	-1.642	18	-2.318	18	-2.321	18	-1.663	18	-1.695
5 CCW	60	-2.257							60	-2.292
10 CCW	120	-3.953							120	-3.988
15 CCW	180	-4.860							180	-4.889
20 CCW	240	-5.674							240	-5.763
25 CCW	300	-6.378							300	-6.403
30 CCW	360	-7.102	360	-7.102	360	-7.144	360	-7.143	360	-7.142
35 CCW	420	-7.800	420	-7.807	420	-7.852	420	-7.842	420	-7.832
30 CCW	360	-7.497	360	-7.537	360	-7.578	360	-7.548	360	-7.556
25 CCW	300	-7.110							300	-7.142
20 CCW	240	-6.503							240	-6.532
15 CCW	180	-5.814							180	-5.828
10 CCW	120	-4.958							120	-5.003
5 CCW	60	-3.982							60	-4.020
0 (CCW)	18	-3.102	18	-3.113	18	-3.103	18	-3.129	18	-3.018

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TABLE 2 (Continued)

Date 8/15
Hex Ball Specimen No. 4
Hex Ball Housing Specimen No. 4
Run No. 13

Set Point & Direction	CYCLE NO. 6 Applied Torque	CYCLE NO. 6 Angle	CYCLE NO. 7 Applied Torque	CYCLE NO. 7 Angle	CYCLE NO. 8 Applied Torque	CYCLE NO. 8 Angle	CYCLE NO. 9 Applied Torque	CYCLE NO. 9 Angle	CYCLE NO. 10 Applied Torque	CYCLE NO. 10 Angle
0 (CW)	19	+3.050	19	+3.065	19	+3.089	19	+3.106	19	+3.185
5 CW									60	+4.751
10 CW									120	+5.487
15 CW									180	+6.400
20 CW									240	+7.215
25 CW									300	+7,943
30 CW	360	+8.686	360	+8.725	360	+8.690	360	+8.711	360	+8.682
35 CW	420	+9.388	420	+9,450	420	+9.382	420	+9.374	420	+9.382
30 CW	360	+9.120	360	+9.210	360	+9.156	360	+9.140	360	+9.129
25 CW									300	+8.755
20 CW									240	+8.206
15 CW									180	+7.549
10 CW									120	+6.823
5 CW									60	+5.828
0 (CW)	20	+4.975	19	+4.884	20	+5.027	20	+5.004	20	+5.007
0 (CCW)	18	-2.192	18	-2.373	18	-2.371	18	-2.457	18	-2.539
5 CCW									60	-3.045
10 CCW									120	-4.069
15 CCW									180	-4.933
20 CCW									240	-5.712
25 CCW									300	-6.509
30 CCW	360	-7.154	360	-7.208	360	-7.171	360	-7.161	360	-7.170
35 CCW	420	-7.820	420	-7.862	420	-7.861	420	-7.849	420	-7.898
30 CCW	360	-7.548	360	-7.565	360	-7.552	360	-7.581	360	-7.617
25 CCW									300	-7.211
20 CCW									240	-6.570
15 CCW									180	-5.905
10 CCW									120	-5.078
5 CCW									60	-4.123
0 (CCW)	18	-3.132	18	-3.187	18	-4.185	18	-3.179	18	-4.216

TABLE 2

Date 8/16

Hex Ball Specimen No. 4

Hex Ball Housing Specimen No. 4

Run No. 14

Set Point & Direction	CYCLE NO. 1 Applied Torque	CYCLE NO. 1 Angle	CYCLE NO. 2 Applied Torque	CYCLE NO. 2 Angle	CYCLE NO. 3 Applied Torque	CYCLE NO. 3 Angle	CYCLE NO. 4 Applied Torque	CYCLE NO. 4 Angle	CYCLE NO. 5 Applied Torque	CYCLE NO. 5 Angle
0 (CW)	19	+3.059	19	+3.065	19	+3.137	19	+3.091	19	+3.136
5 CW	60	+4.889							60	+4.770
10 CW	120	+5.540							120	+5.502
15 CW	180	+6.388							180	+6.365
20 CW	240	+7.181							240	+7.168
25 CW	300	+7.910							300	+7.916
30 CW	360	+8.642	360	+8.667	360	+8.670	360	+8.650	360	+8.633
35 CW	420	+9.334	420	+9.353	420	+9.348	420	+9.345	420	+9.324
30 CW	360	+9.110	360	+9.132	360	+9.112	360	+9.124	360	+9.084
25 CW	300	+8.745							300	+8.723
20 CW	240	+8.195							240	+8.150
15 CW	180	+7.558							180	+7.516
10 CW	120	+6.750							120	+6.769
5 CW	60	+5.800							60	+5.794
0 (CW)	20	+4.976	20	+4.967	20	+4.938	20	+4.954	20	+4.960
0 (CCW)	18	-2.513	18	-2.394	18	-2.149	18	-2.406	18	-2.498
5 CCW	60	-3.149							60	-3.128
10 CCW	120	-4.062							120	-4.099
15 CCW	180	-4.932							180	-4.977
20 CCW	240	-5.751							240	-5.841
25 CCW	300	-6.471							300	-6.581
30 CCW	360	-7.197	360	-7.258	360	-7.286	360	-7.236	360	-7.238
35 CCW	420	-7.912	420	-7.942	420	-7.946	420	-7.961	420	-7.965
30 CCW	360	-7.645	360	-7.664	360	-7.669	360	-7.669	360	-7.636
25 CCW	300	-7.224							300	-7.269
20 CCW	240	-6.609							240	-6.651
15 CCW	180	-5.908							180	-5.960
10 CCW	120	-5.067							120	-5.126
5 CCW	60	-4.066							60	-4.145
0 (CCW)	18	-3.125	18	-3.182	18	-3.196	18	-3.206	18	-3.221

TABLE 2 (Continued)

Date 8/16
Hex Ball Specimen No. 4
Hex Ball Housing Specimen No. 4
Run No. 14

Set Point & Direction	CYCLE NO. 6 Applied Torque	CYCLE NO. 6 Angle	CYCLE NO. 7 Applied Torque	CYCLE NO. 7 Angle	CYCLE NO. 8 Applied Torque	CYCLE NO. 8 Angle	CYCLE NO. 9 Applied Torque	CYCLE NO. 9 Angle	CYCLE NO. 10 Applied Torque	CYCLE NO. 10 Angle
0 (CW)	19	+3.146	19	+3.066	19	+3.135	18	+3.148	18	+3.194
5 CW									60	+4.802
10 CW									120	+5.608
15 CW									180	+6.411
20 CW									240	+7.213
25 CW									300	+7.937
30 CW	360	+8.654	360	+8.671	360	+8.659	360	+8.619	360	+8.631
35 CW	420	+9.329	420	+9.368	420	+9.332	420	+9.318	420	+9.341
30 CW	360	+9.093	360	+9.112	360	+9.107	360	+9.071	360	+9.105
25 CW									300	+8.729
20 CW									240	+8.179
15 CW									180	+7.537
10 CW									120	+6.790
5 CW									60	+5.800
0 (CW)	20	+4.943	20	+4.970	20	+4.950	19	+4.954	19	+4.960
0 (CCW)	18	-2.548	18	-2.524	18	-2.401	18	-2.495	18	-2.505
5 CCW									60	-3.126
10 CCW									120	-4.167
15 CCW									180	-5.092
20 CCW									240	-5.789
25 CCW									300	-6.518
30 CCW	360	-7.246	360	-7.274	360	-7.267	360	-7.306	360	-7.245
35 CCW	420	-7.924	420	-7.948	420	-6.940	420	-7.962	420	-7.965
30 CCW	360	-7.566	360	-7.660	360	-7.653	360	-7.681	360	-7.678
25 CCW									300	-7.267
20 CCW									240	-6.646
15 CCW									180	-5.955
10 CCW									120	-5.130
5 CCW									60	-4.146
0 (CCW)	18	-3.209	18	-3.208	18	-3.176	18	-3.200	18	-3.188

TABLE 1

Date 7/30/85
Hex Ball Specimen No. 1
Hex Ball Housing Specimen No. 1
Run No. 15
Direction of Torque Application CW

TORQUE (in-lb)	ANGLE (Degrees)	REMARKS (Record maximum torque applied, any significant observations)
019	3.366	ATTACHED TURNBUCKLE
025	3.505	
060	3.985	
123	4.857	
180	5.512	
240	6.126	
300	6.765	
360	7.381	
420	8.146	
480	8.591	
540	9.576	
600	12.000	DEFINITE SLOPE CHANGE
540	11.864	
480	11.557	
420	11.210	
360	10.820	
300	10.340	
240	9.720	
180	8.979	
120	8.027	
060	6.674	
025	6.115	
019	5.981	

Initial Angle Reading (Repeatability Setup) 3.366 in.-lb

Final Angle Reading (Repeatability Setup) 5.981 in.-lb

TABLE 1

Date 8/5
Hex Ball Specimen No. 2
Hex Ball Housing Specimen No. 2
Run No. 16
Direction of Torque Application CW

TORQUE (in-lb)	ANGLE (Degrees)	REMARKS (Record maximum torque applied, any significant observations)
19	+3.422	
60	+3.840	
120	+5.596	
180	+6.435	
240	+7.174	
300	+7.918	
360	+8.607	
420	+9.398	
480	+10.100	
500	10.387	
515	10.551	
530	10.809	
545	11.143	
560	11.338	
575	11.558	
590	11.979	
605	12.336	
620	12.609	
635	13.336	
650	13.640	
665	14.295	
600	14.095	
500	13.509	
400	12.933	
300	12.100	
200	11.189	
100	9.541	
60	8.765	
20	7.775	

Initial Angle Reading (Repeatability Setup)_____

Final Angle Reading (Repeatability Setup)_____

TABLE 1

Date 8/21
Hex Ball Specimen No. 3
Hex Ball Housing Specimen No. 3
Run No. 17
Direction of Torque Application CW

TORQUE (in-lb)	ANGLE (Degrees)	REMARKS (Record maximum torque applied, any significant observations)
019	5.680	
100	6.879	
200	8.089	
300	9.217	
400	10.277	
500	11.670	
525	11.820	
550	12.243	
575	12.530	
600	12.976	
625	13.400	
650	14.060	
675	14.876	
700	15.753	
600	15.516	
500	14.984	
400	14.308	
300	13.432	
200	12.134	
100	10.541	
020	8.648	

Initial Angle Reading (Repeatability Setup)_____

Final Angle Reading (Repeatability Setup)_____

TABLE 1

Date 8-19-85
Hex Ball Specimen No. 4
Hex Ball Housing Specimen No. 4
Run No. 18
Direction of Torque Application CW

TORQUE (in-lb)	ANGLE (Degrees)	REMARKS (Record maximum torque applied, any significant observations)
019	-7.890	
100	-5.316	
200	-3.824	
300	-2.617	
400	-1.430	
500	-0.105	
525	+0.320	
550	+0.715	
575	1.111	
600	1.550	
625	1.970	
650	2.560	
675	3.147	
700	3.945	
600	3.571	
500	2.996	
400	2.280	
300	+1.240	
200	-0.064	
100	-1.689	
019	-3.530	

Initial Angle Reading (Repeatability Setup)_____

Final Angle Reading (Repeatability Setup)_____

TABLE 1

Date 7/10
Hex Ball Specimen No. 1
Hex Ball Housing Specimen No. 1
Run No. 19
Direction of Torque Application

TORQUE (in-lb)	ANGLE (Degrees)	REMARKS (Record maximum torque applied, any significant observations)
20	-5.050	
100	-3.814	
200	-3.591	
300	-1.476	
400	-0.417	
500	+0.625	
600	+1.859	
700	+3.809	
725	+4.779	
750	+5.876	
766	+7.292	
700	+7.018	
600	+6.474	
500	+5.869	
400	+5.165	
300	+4.134	
200	+2.755	
100	+1.030	
20	-0.950	

Initial Angle Reading (Repeatability Setup)

Final Angle Reading (Repeatability Setup)

TABLE 1

Date 8/22
Hex Ball Specimen No. 2
Hex Ball Housing Specimen No. 2
Run No. 20
Direction of Torque Application

TORQUE (in-lb)	ANGLE (Degrees)	REMARKS (Record maximum torque applied, any significant observations)
19	-7.468	
100	-5.721	
200	-4.047	
300	-2.840	
400	-1.740	
500	-0.645	
600	+0.485	
700	+1.901	
725	+2.250	
750	+2.745	
775	+3.222	
800	+3.680	
825	+4.219	
850	+4.805	
875	+5.435	
900	+7.385	
925	+7.642	
950	+8.260	
975	+9.900	
1000	+12.046	
1025		
1050		
1092	Failure	

Initial Angle Reading (Repeatability Setup)

Final Angle Reading (Repeatability Setup)

TABLE 1

Date 8/23
Hex Ball Specimen No. 3
Hex Ball Housing Specimen No. 3
Run No. 21
Direction of Torque Application

TORQUE (in-lb)	ANGLE (Degrees)	REMARKS (Record maximum torque applied, any significant observations)
019	-9.854	
100	-8.328	
200	-6.909	
300	-5.472	
400	-4.623	
500	-3.485	
550	-2.910	
600	-2.389	
650	-1.808	
700	-1.170	
725	-0.753	
750	-0.367	
775	+0.091	
800	+0.618	
825	+1.226	
850	+1.990	
875	+2.571	
900	+3.338	
925	+4.058	
950	+5.3	
975	+6.176	
1000	+8.540	
1025	+9.071	
1050		
1121	Failure	

Initial Angle Reading (Repeatability Setup)

Final Angle Reading (Repeatability Setup)

TABLE 1

Date 8/26
Hex Ball Specimen No. 4
Hex Ball Housing Specimen No. 4
Run No. 22
Direction of Torque Application

TORQUE (in-lb)	ANGLE (Degrees)	REMARKS (Record maximum torque applied, any significant observations)
19	-9.296	
100	-7.125	
200	-5.674	
300	-4.347	
400	-3.236	
500	-2.105	
600	-0.872	
650	-0.294	
700	+0.503	
725	+0.920	
750	+1.006	
775	+1.012	
800	+1.190	
825	+1.703	
850	+2.203	
875	+4.467	
900	+4.446	
925	+4.651	
950	+5.201	
975	+6.312	
1000	+7.492	
1025	+8.695	
1056	Failure	

Initial Angle Reading (Repeatability Setup)

Final Angle Reading (Repeatability Setup)

TABLE 1

Date 8-26-85
Hex Ball Specimen No. 1
Hex Ball Housing Specimen No. 2
Run No. 23 (19.5)
Direction of Torque Application CW

TORQUE (in-lb)	ANGLE (Degrees)	REMARKS (Record maximum torque applied, any significant observations)
019	-19.650	
108	-18.009	
170	-17.003	
240	-16.002	
321	-15.005	
400	-14.004	
481	-13.000	
555	-12.000	
621	-11.009	
686	-10.003	
749	-9.006	
802	-8.007	
851	-7.001	
887	-6.008	
855	-6.000	CHANGED TURNBUCKLE
917	-5.005	
947	-4.001	
956	-3.000	
972	-2.044	
986	-1.602	Initial
1002	-0.956	After 1 min. at -1.0/1015
1005	-0.757	After 1 min at -0.8/1016
1005	-0.550	After 1 min at -0.6/1016
1011	-0.166	After 1 min at -0.2/1030
1019	+0.011	After 1 min at 0/1030
1033	+1.018	After 1 min at +1/1047
1049	+2.016	After 1 min at +2/1065

Initial Angle Reading (Repeatability Setup)_____

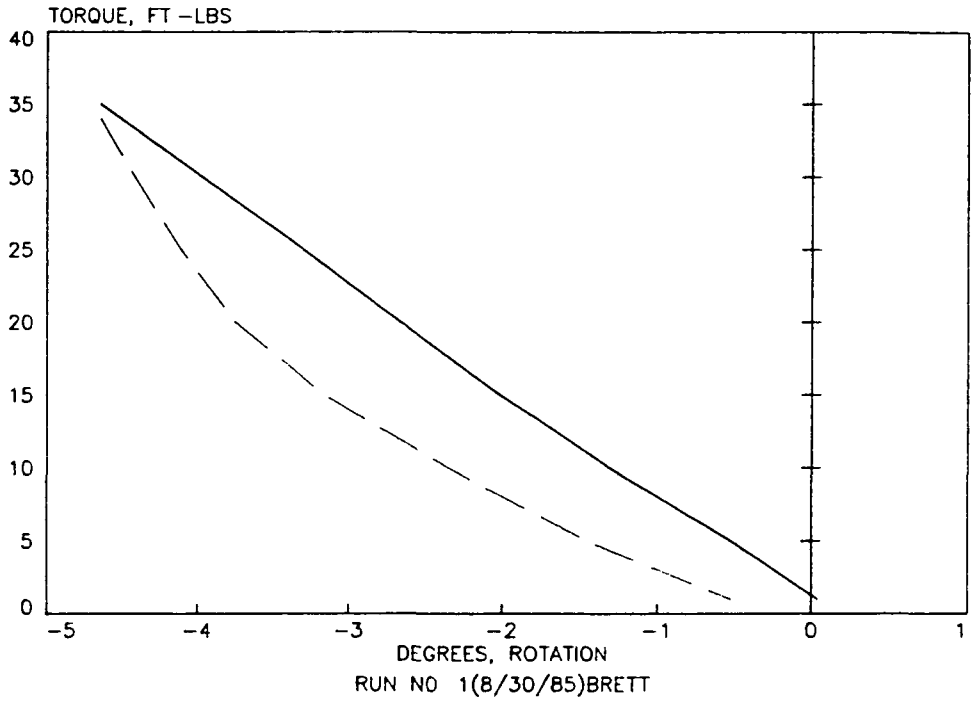
Final Angle Reading (Repeatability Setup)_____

APPENDIX C

PLOTTED DATA FROM APPENDIX B

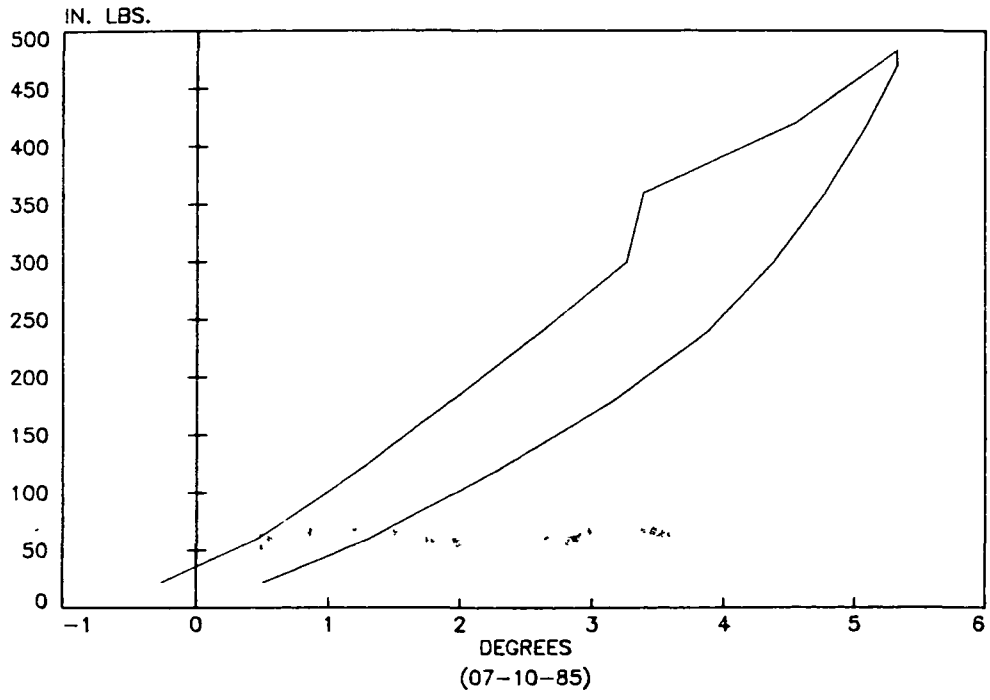
HEX BALL TORQUE TEST, RUN NO. 1
FOR SPACE TELESCOPE

RUN NO 1 CW LOAD ——— RUN NO 1 CW UNLOAD ———

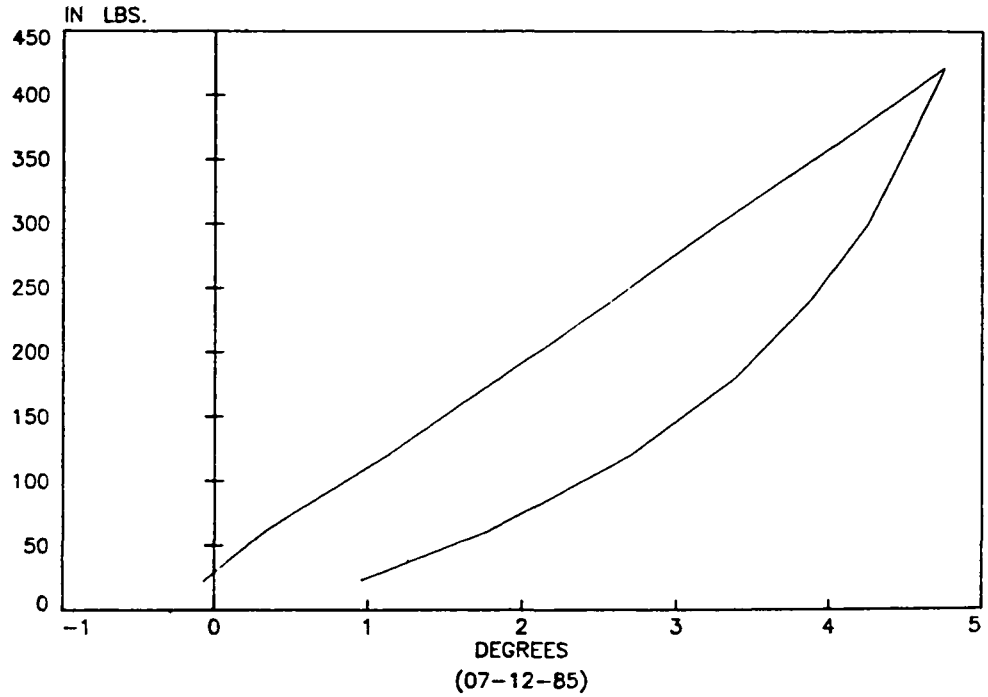


RUN #2, HEX BALL TORQUE EXPERIMENT
TORQUE VS. DEGREE TORSION

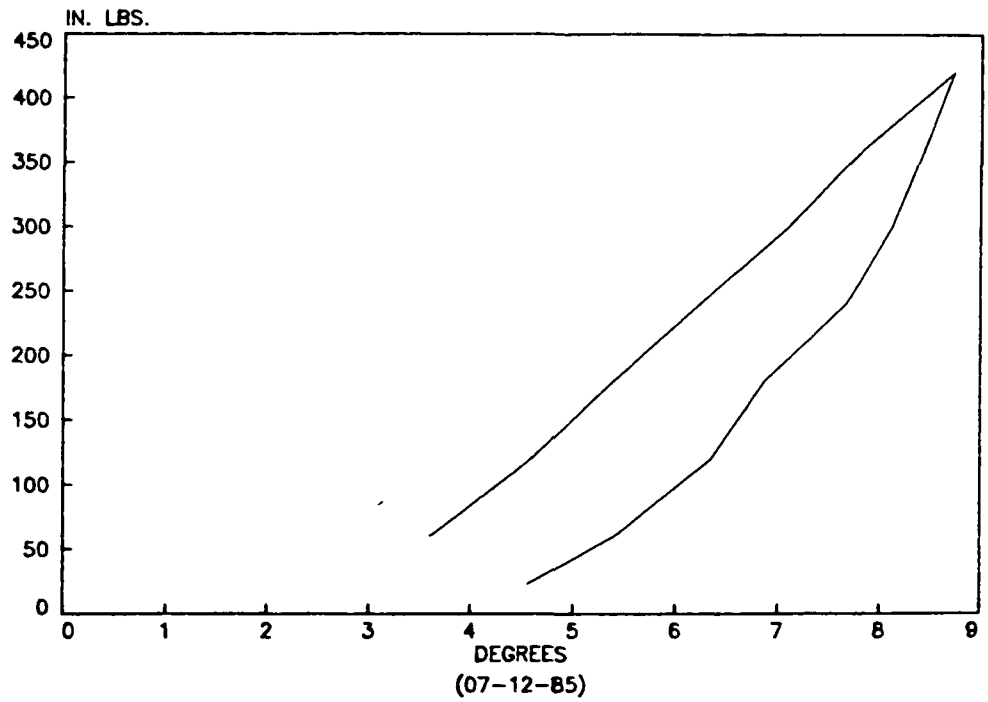
CW LOAD ——— CW UNLOAD ———



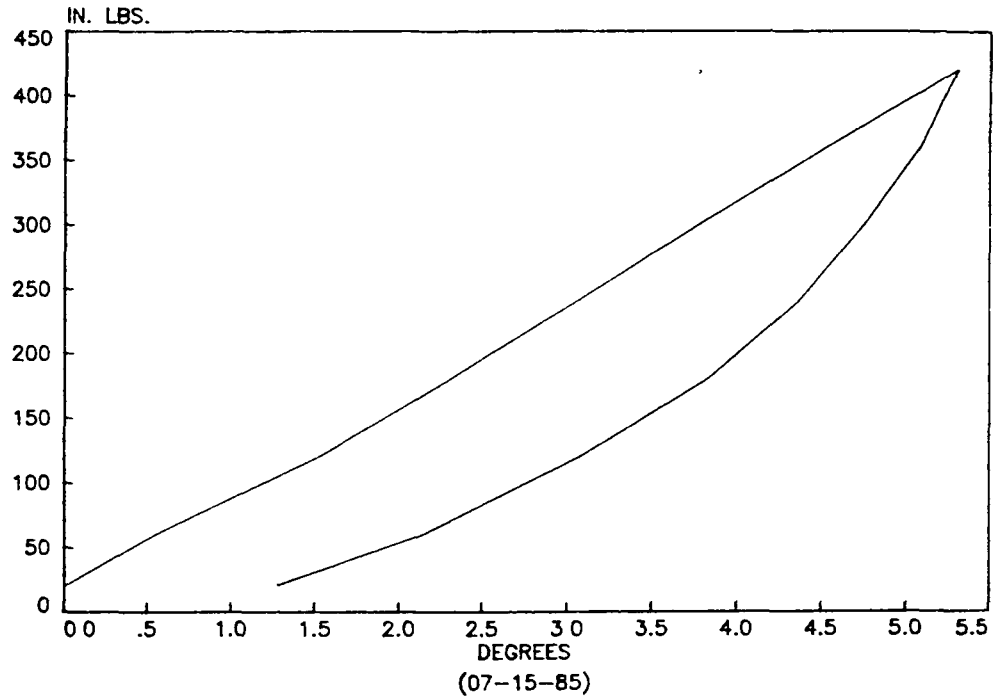
RUN #3, CYCLE 1, HEX BALL TORQUE EXPERIMENT
TORQUE VS. DEGREE TORSION
CW LOAD CCW UNLOAD



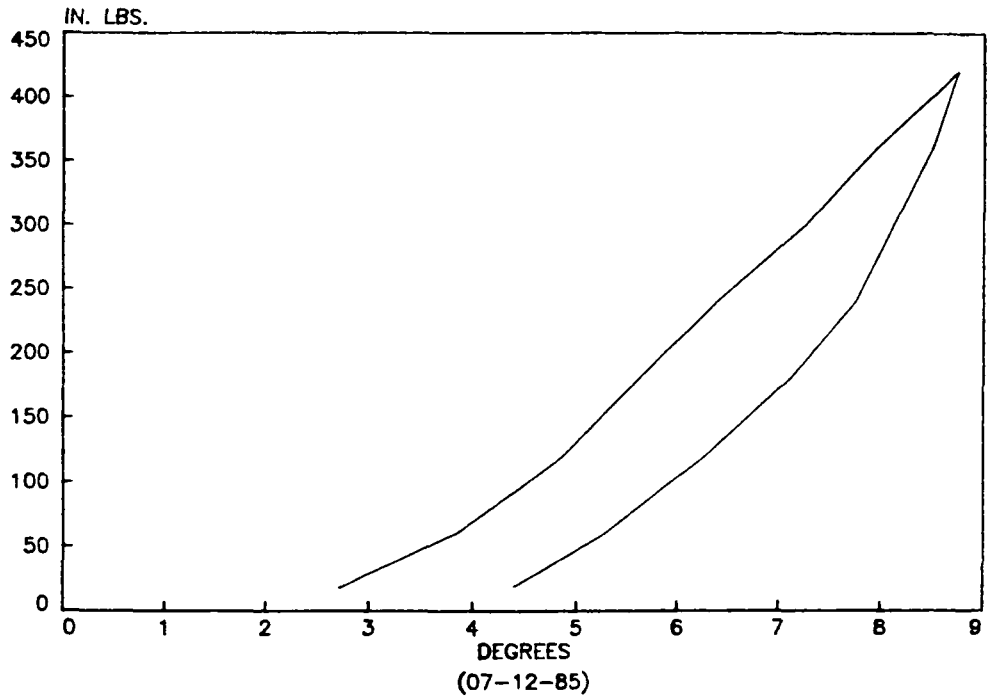
RUN #3, CYCLE 1, HEX BALL TORQUE EXPERIMENT
TORQUE VS. DEGREE TORSION
CCW LOAD CW UNLOAD



RUN #3, CYCLE 2, HEX BALL TORQUE EXPERIMENT
TORQUE VS. DEGREE TORSION
CW LOAD CCW UNLOAD

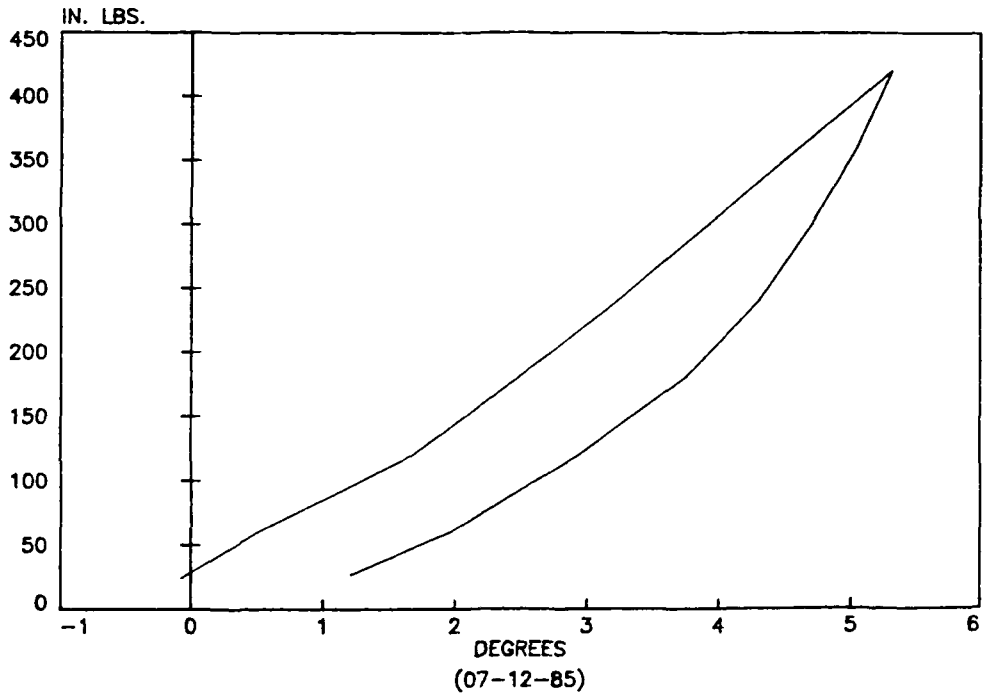


RUN #3, CYCLE 2, HEX BALL TORQUE EXPERIMENT
TORQUE VS. DEGREE TORSION
CCW LOAD CW UNLOAD



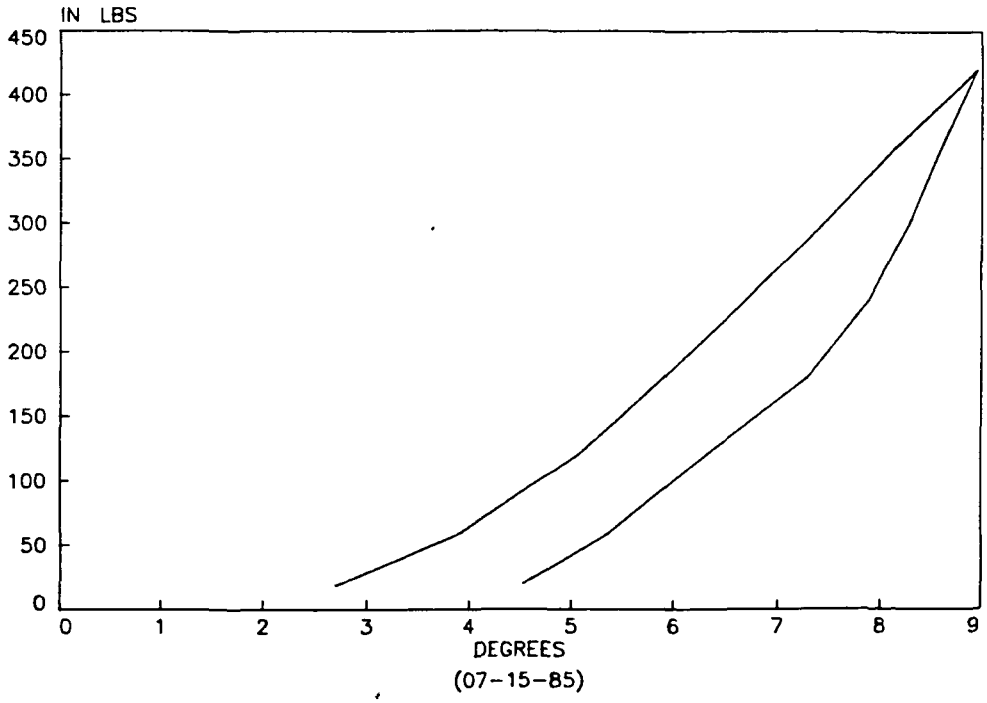
RUN #3, CYCLE 3, HEX BALL TORQUE EXPERINMENT
TORQUE VS. DEGREE TORSION

CW LOAD ——— CCW UNLOAD ———

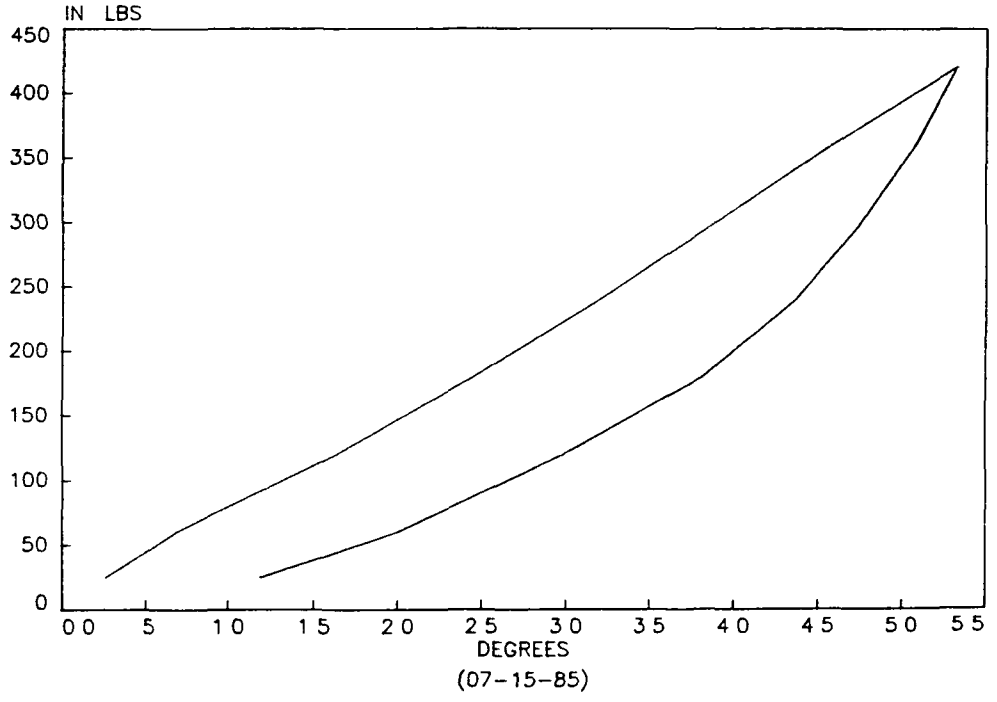


RUN #3, CYCLE 3, HEX BALL TORQUE EXPERIMENT
TORQUE VS. DEGREE TORSION

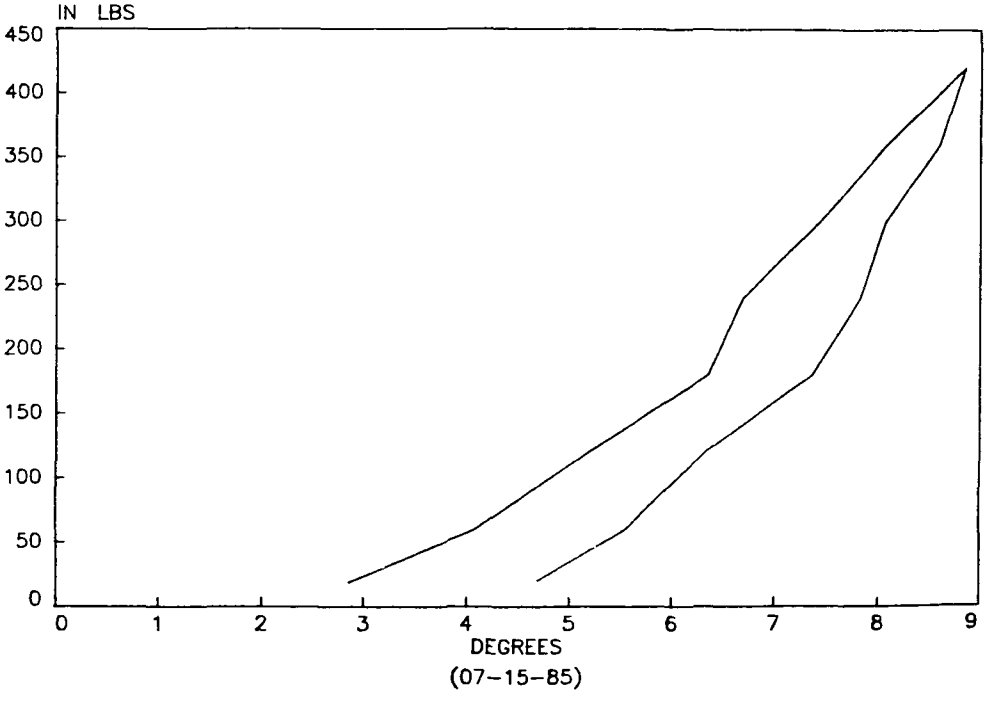
CCW LOAD ——— CW UNLOAD ———



RUN #3, CYCLE 4, HEX BALL TORQUE EXPERIMENT
TORQUE VS. DEGREE TORSION
CW LOAD CCW UNLOAD

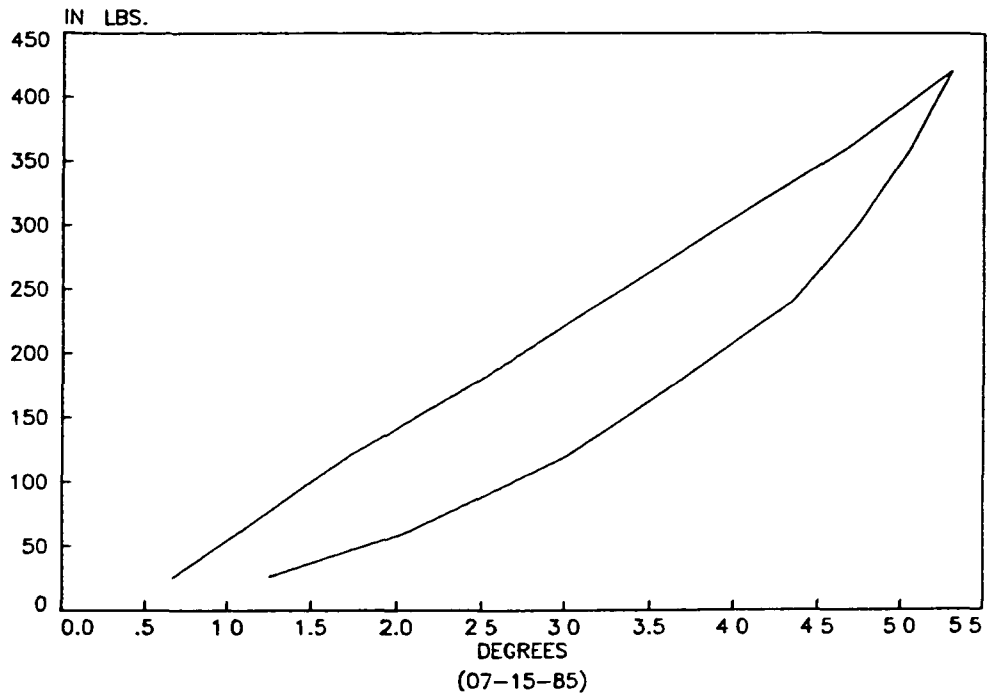


RUN #3, CYCLE 4, HEX BALL TORQUE EXPERIMENT
TORQUE VS. DEGREE TORSION
CCW LOAD CW UNLOAD



RUN #3, CYCLE 5, HEX BALL TORQUE EXPERIMENT
TORQUE VS. DEGREE TORSION

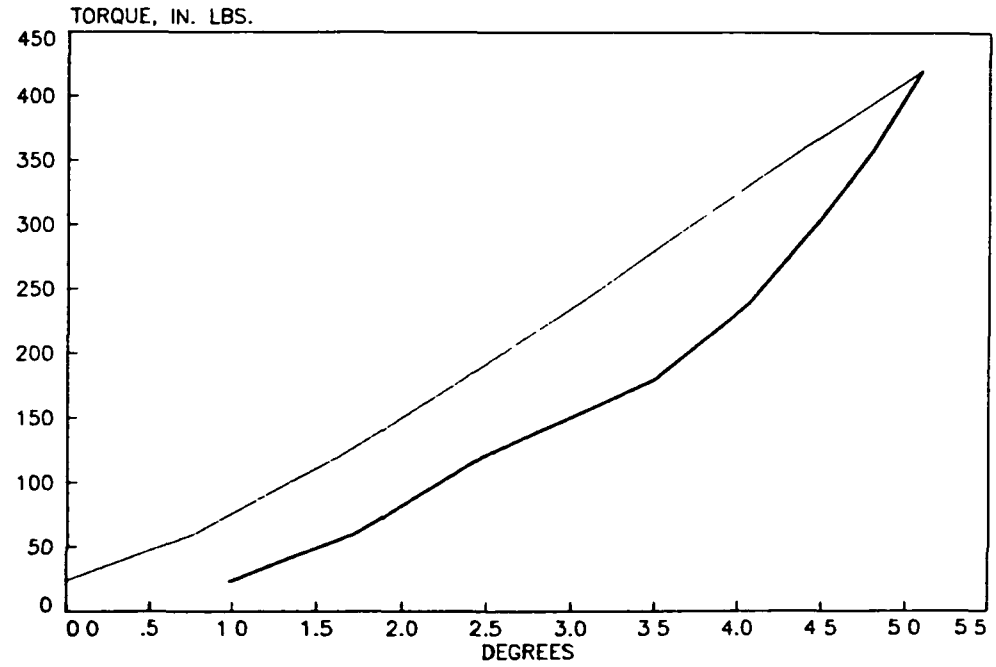
CW LOAD CCW UNLOAD



(07–15–85)

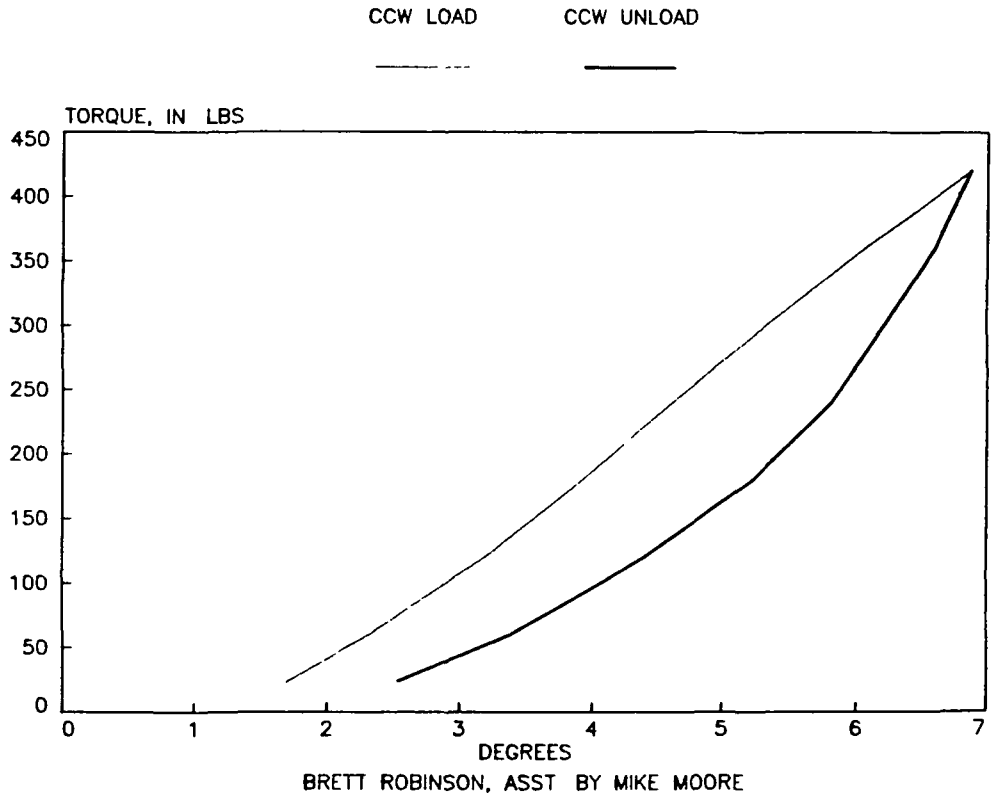
HEX BALL TORQUE TEST RUN #4, CYCLE #1

CW LOAD CW UNLOAD



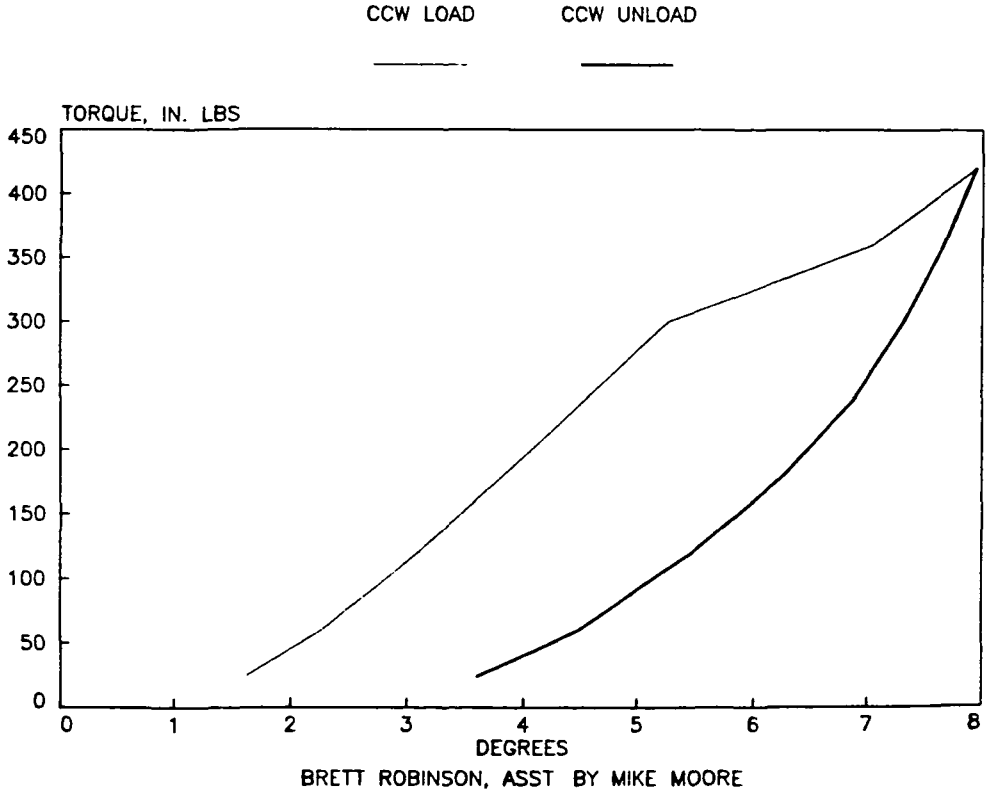
BRETT ROBINSON , ASST BY MIKE MOORE

HEX BALL TORQUE TEST RUN #4, CYCLE #1



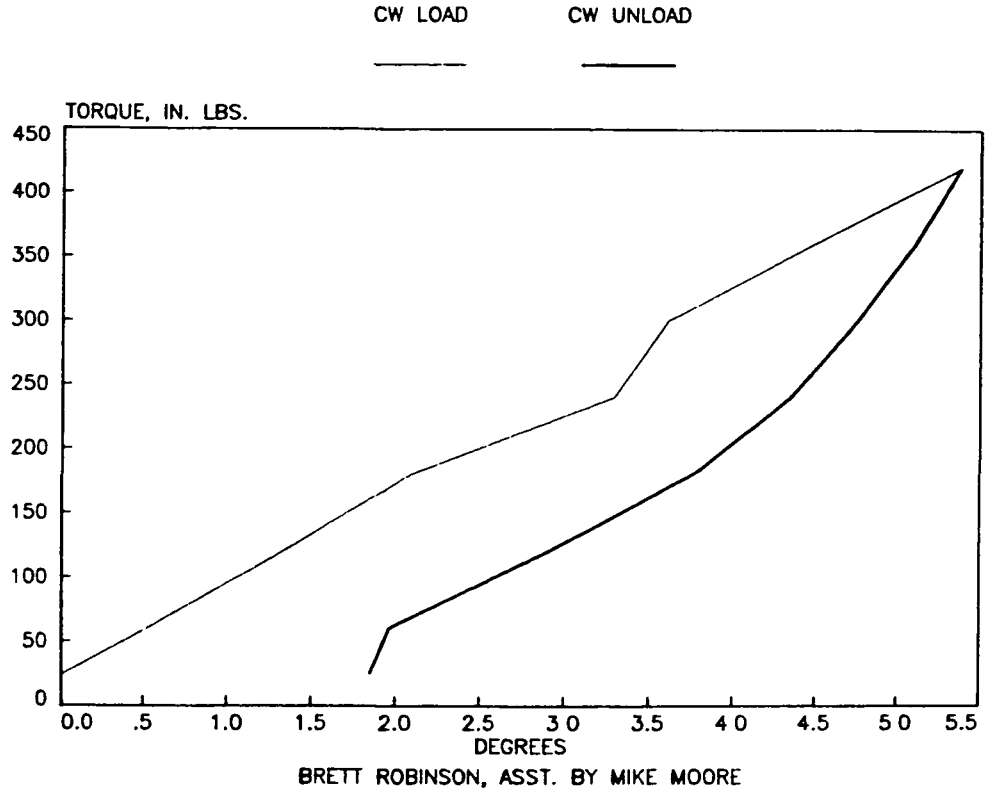
BRETT ROBINSON, ASST BY MIKE MOORE

HEX BALL TORQUE TEST RUN #4, CYCLE #2



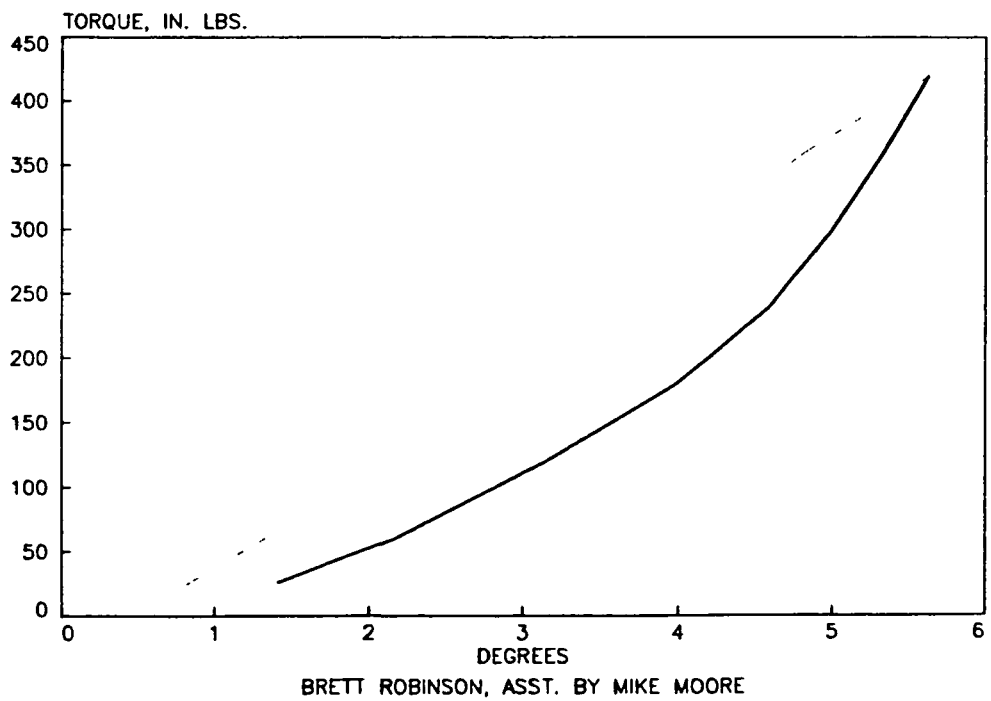
BRETT ROBINSON, ASST BY MIKE MOORE

HEX BALL TORQUE TEST RUN #4, CYCLE #2



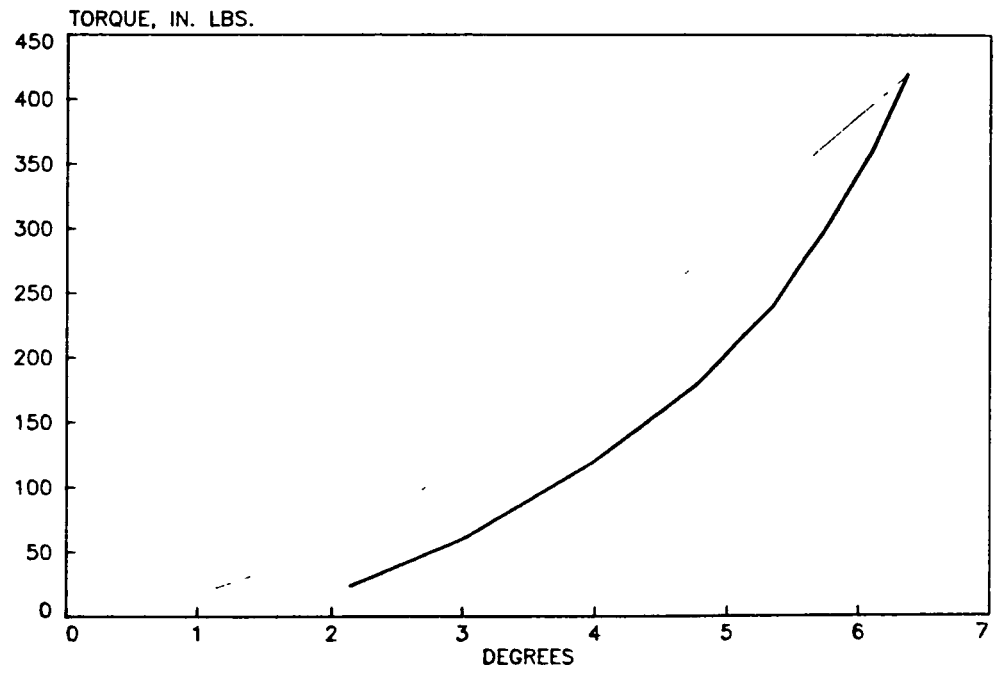
BRETT ROBINSON, ASST. BY MIKE MOORE

HEX BALL TORQUE TEST RUN #4, CYCLE #3

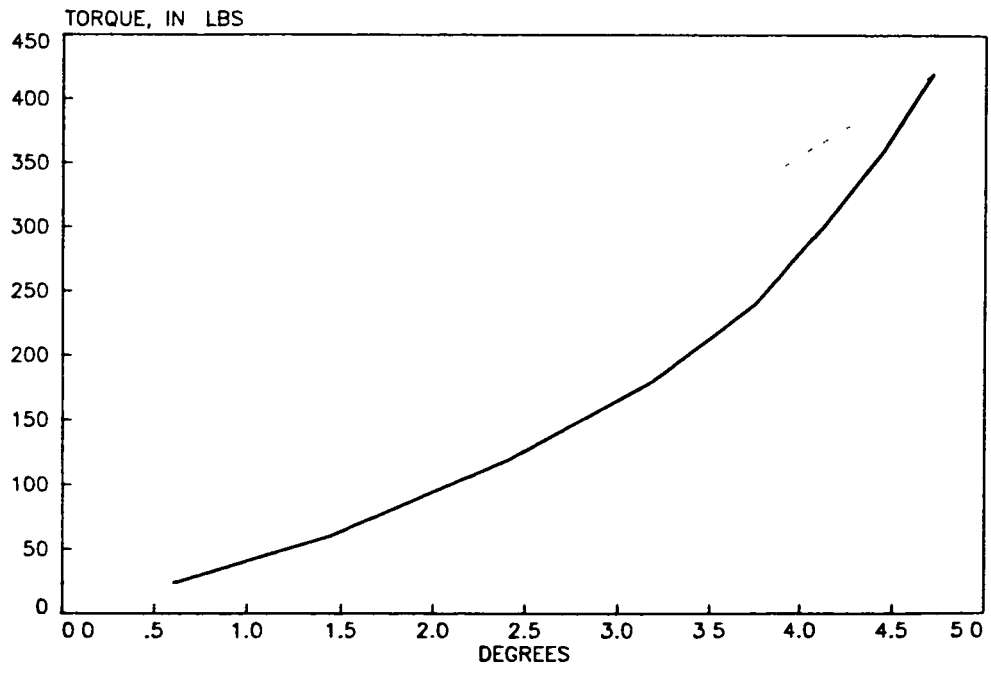


BRETT ROBINSON, ASST. BY MIKE MOORE

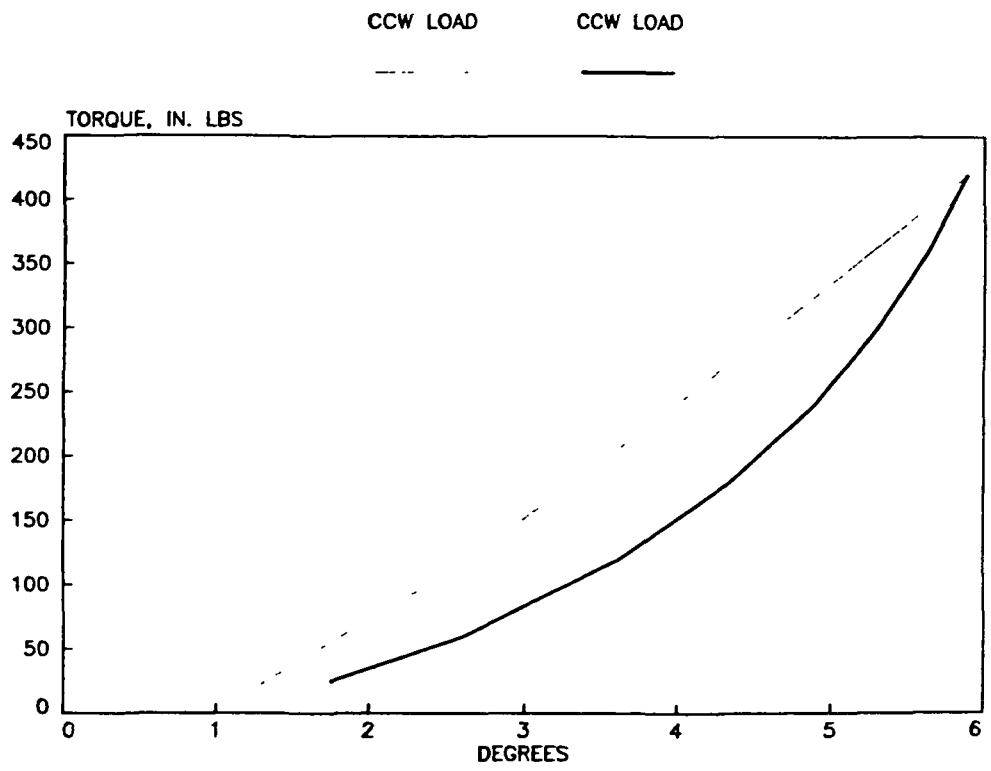
HEX BALL TORQUE TEST RUN #4, CYCLE #3



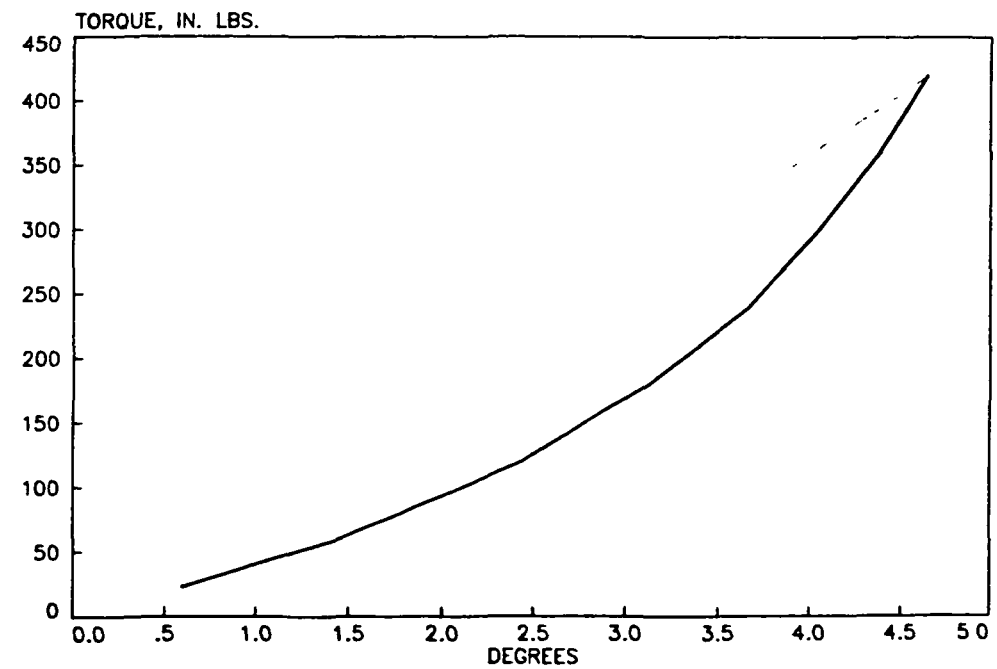
HEX BALL TORQUE TEST RUN #4, CYCLE #4



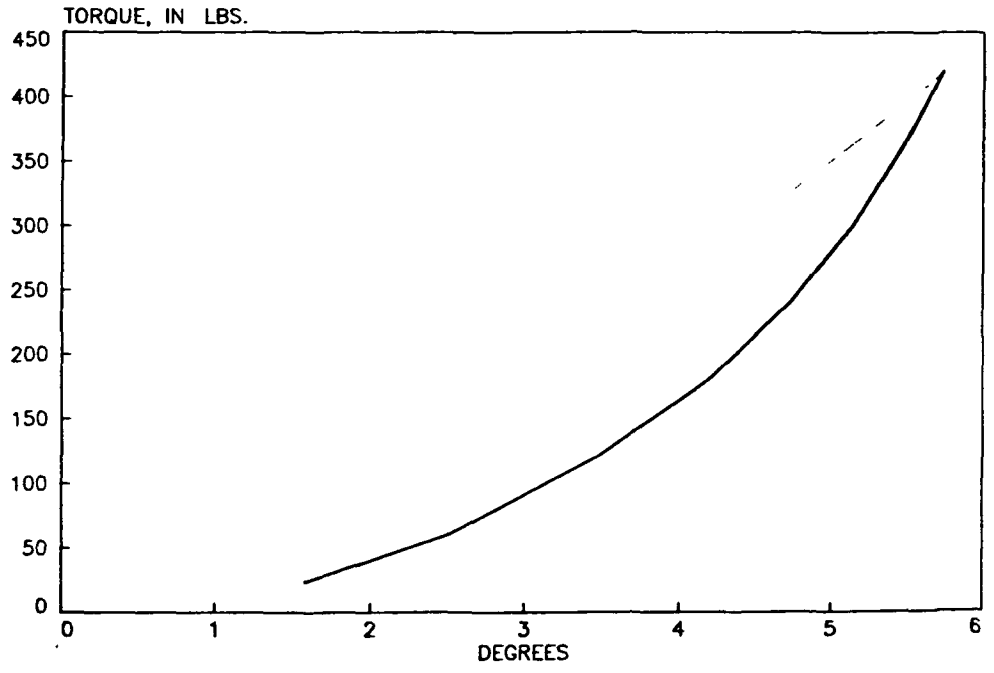
HEX BALL TORQUE TEST RUN #4, CYCLE #4



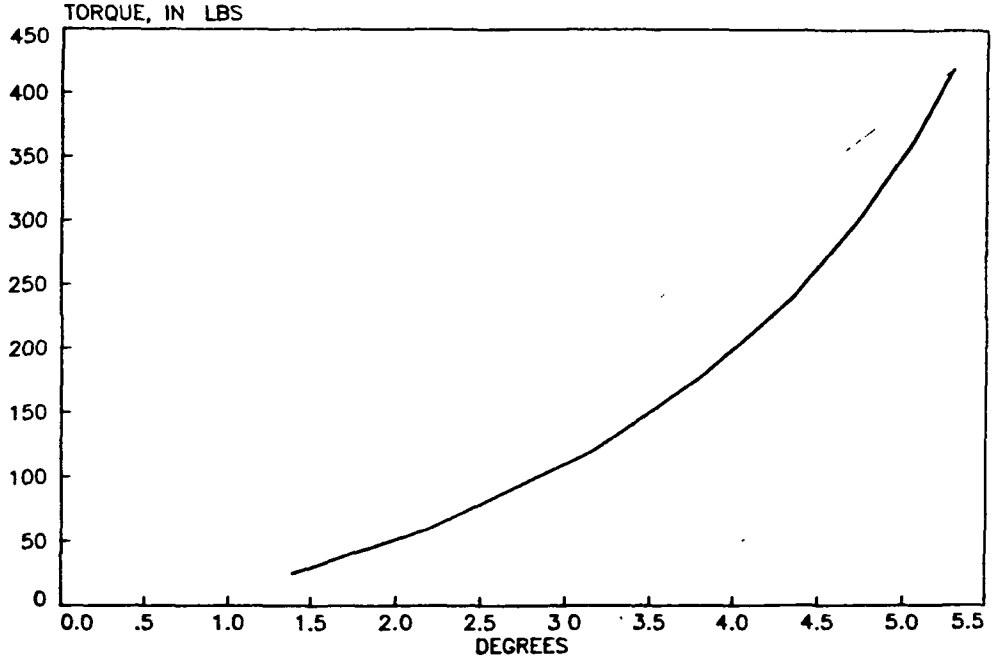
HEX BALL TORQUE TEST RUN #4, CYCLE #5



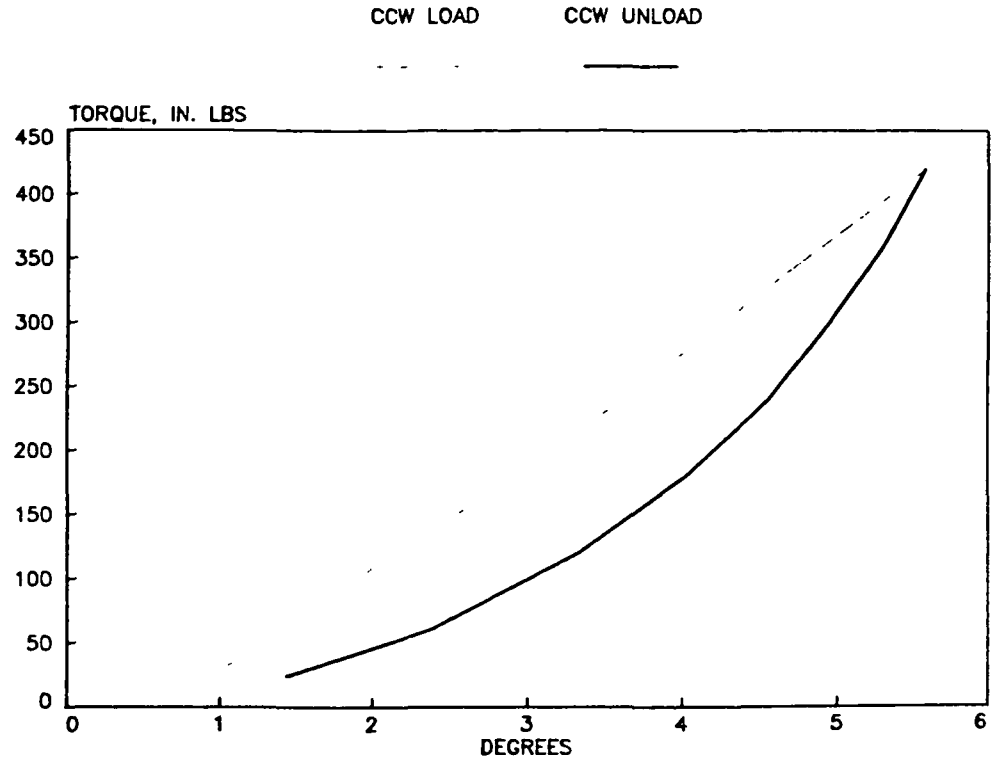
HEX BALL TORQUE TEST RUN #4, CYCLE #5



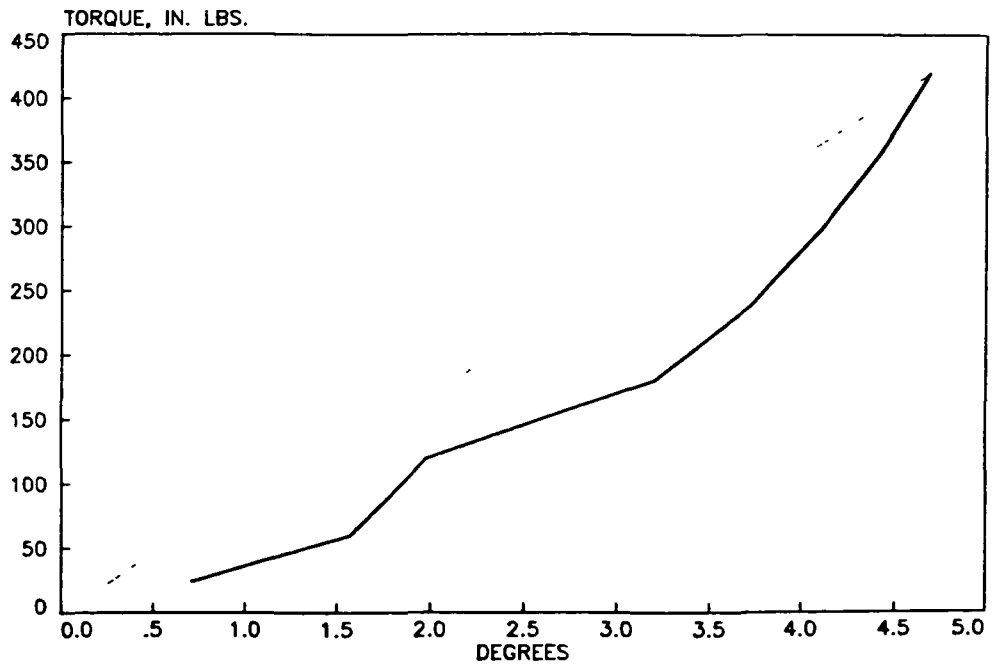
HEX BALL TORQUE TEST RUN #4, CYCLE #6



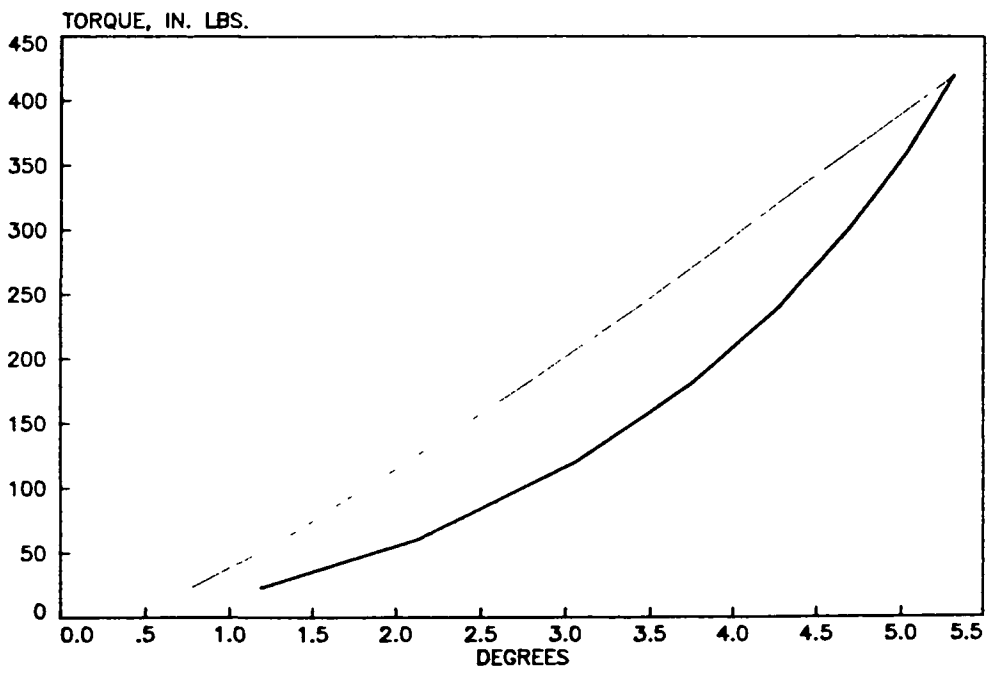
HEX BALL TORQUE TEST RUN #4, CYCLE #6



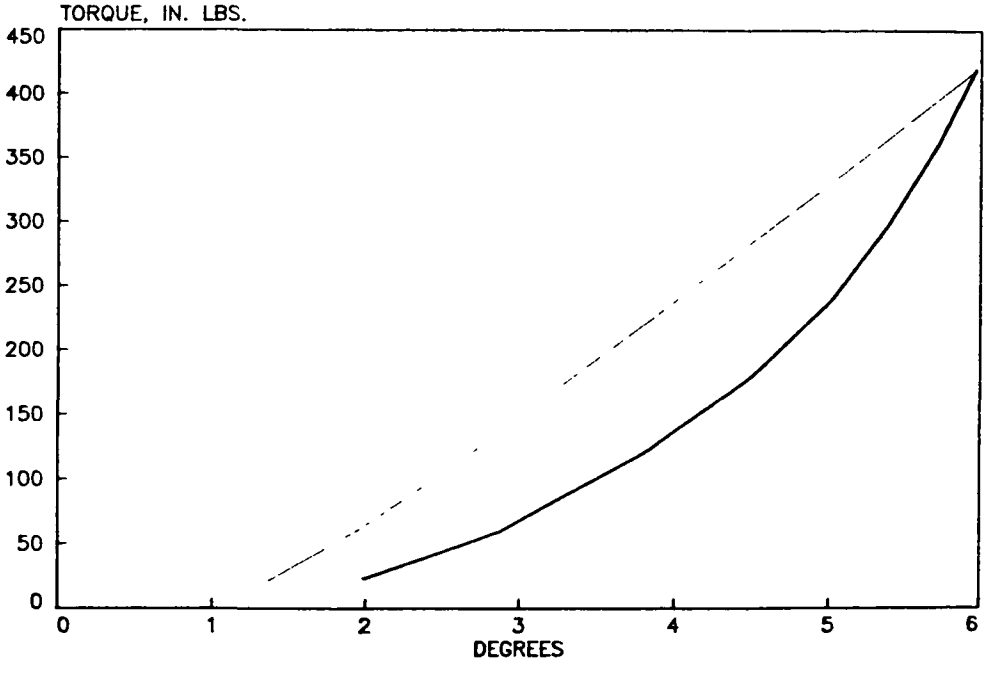
HEX BALL TORQUE TEST RUN #4, CYCLE #7



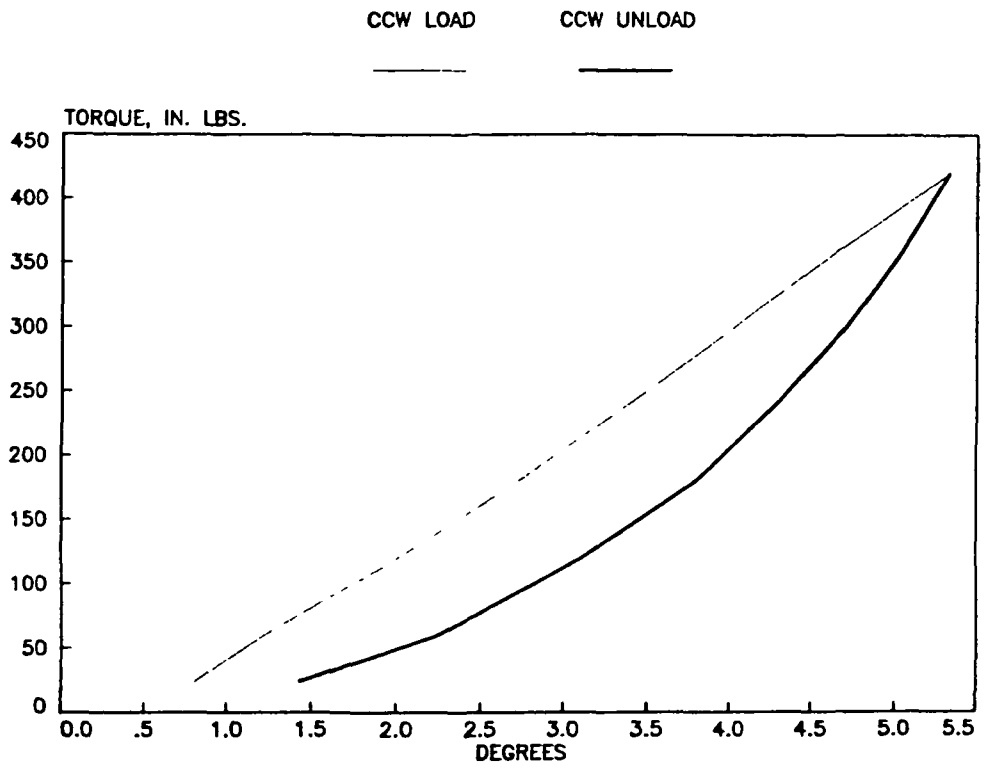
HEX BALL TORQUE TEST RUN #4, CYCLE #7



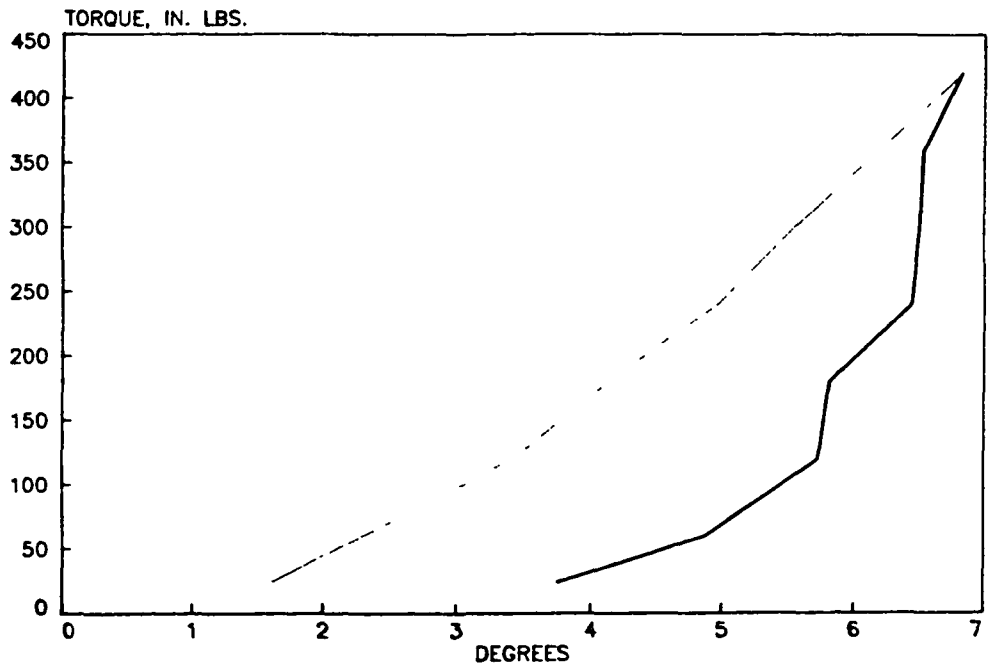
HEX BALL TORQUE TEST RUN #4, CYCLE #8



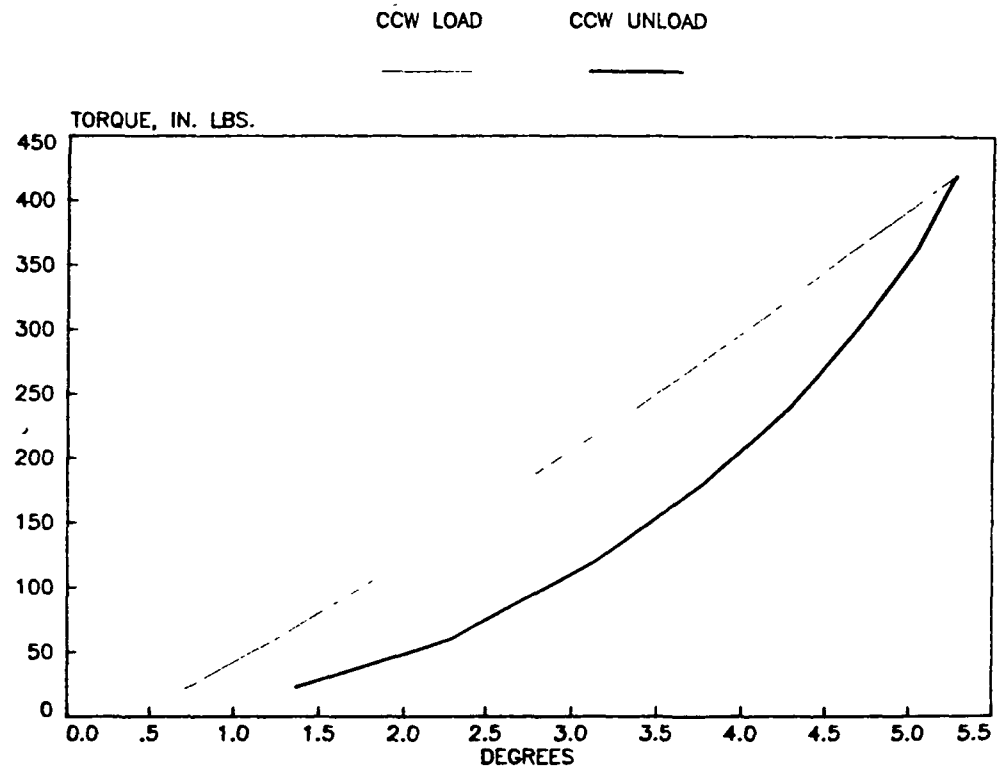
HEX BALL TORQUE TEST RUN #4, CYCLE #8



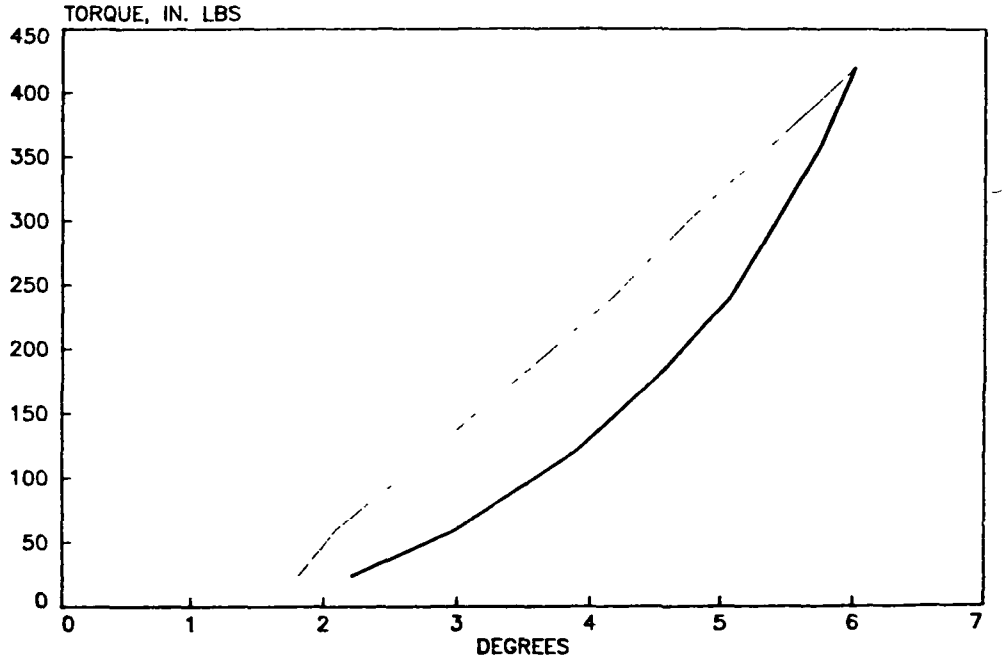
HEX BALL TORQUE TEST RUN #4, CYCLE #10



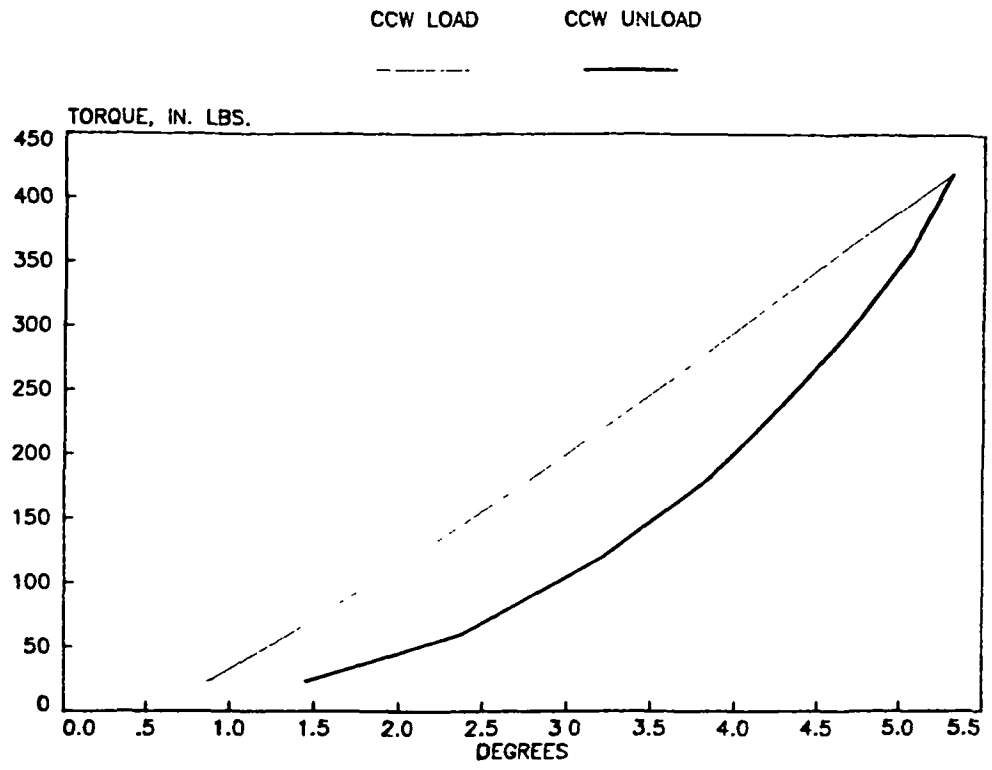
HEX BALL TORQUE TEST RUN #4, CYCLE #10



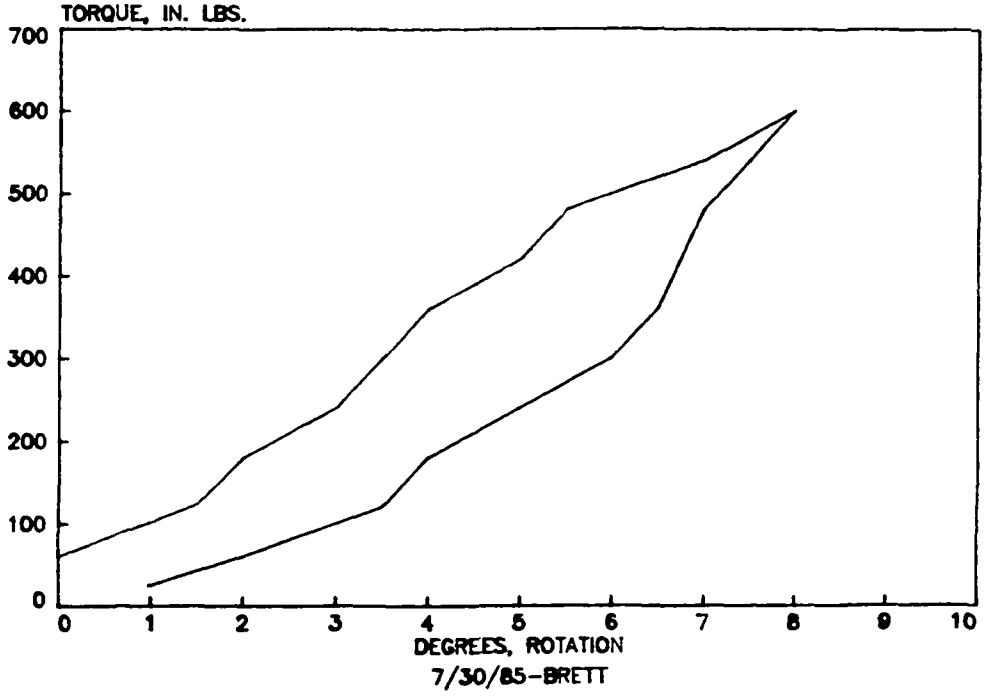
HEX BALL TORQUE TEST RUN #4, CYCLE #9



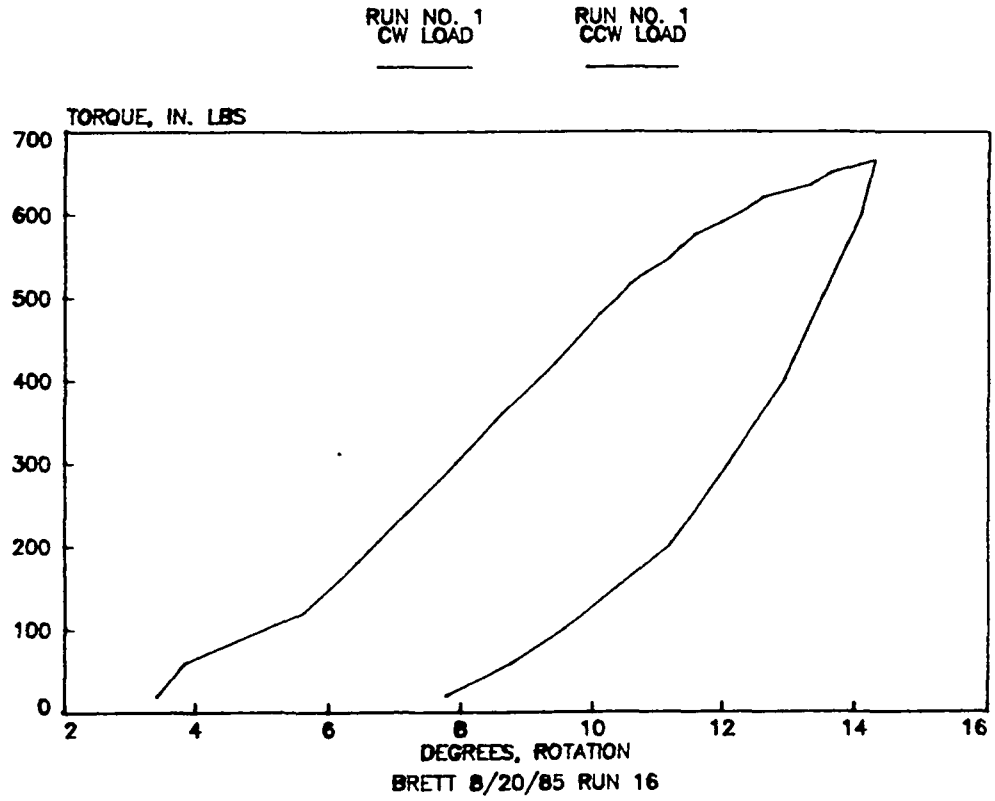
HEX BALL TORQUE TEST RUN #4, CYCLE #9



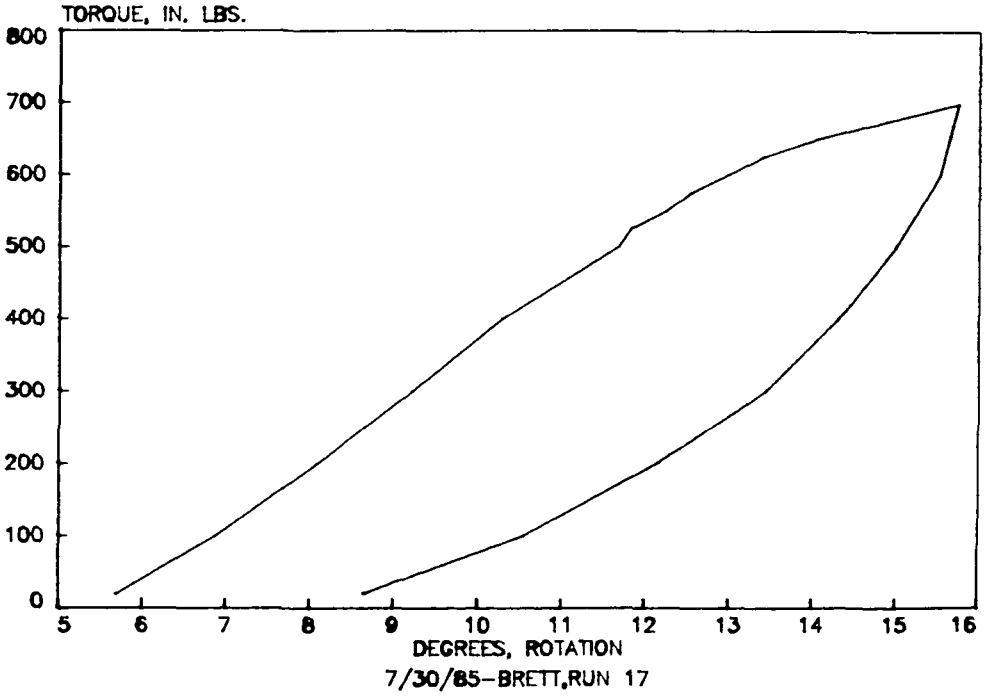
HEX BALL TORQUE TEST, RUN #15 FOR SPACE TELESCOPE



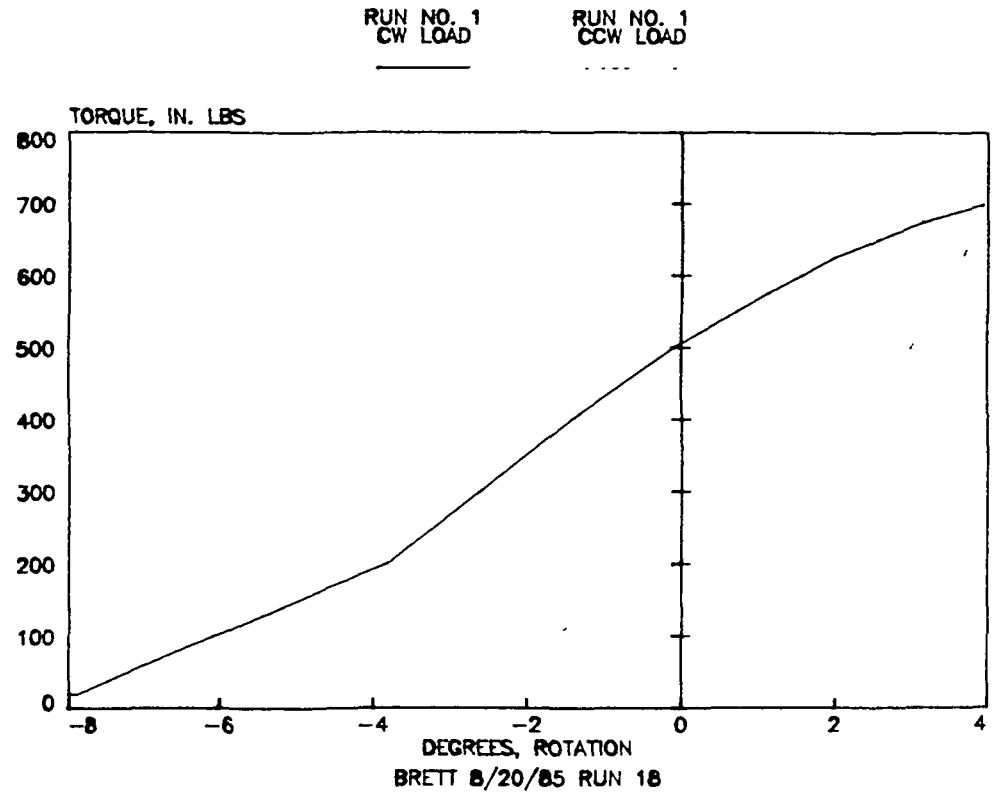
HEX BALL TORQUE TEST



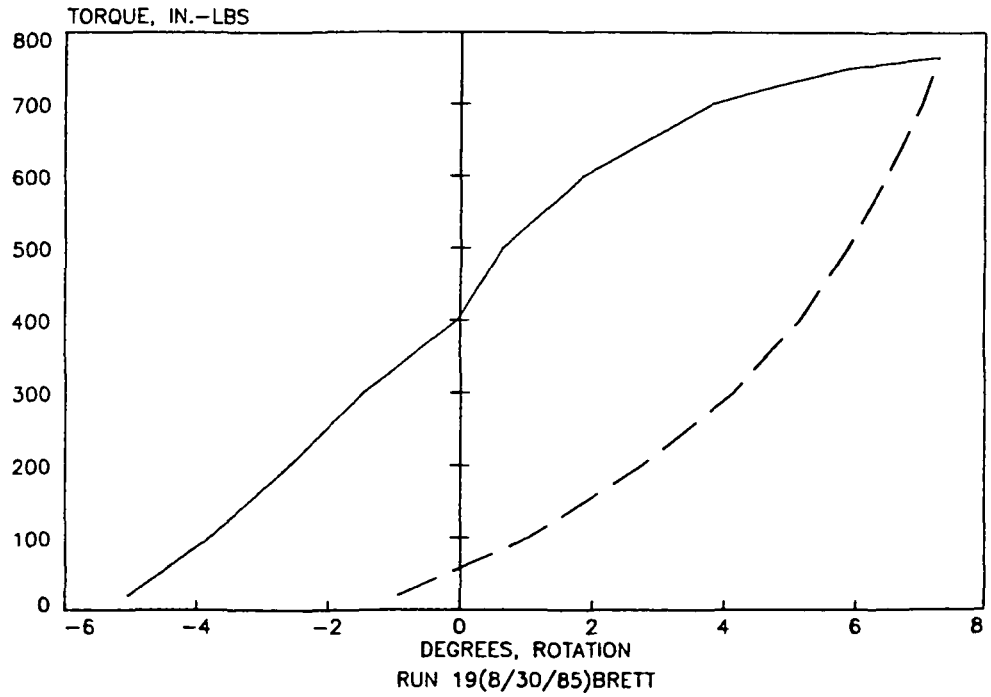
HEX BALL TORQUE TEST, RUN #17
FOR SPACE TELESCOPE



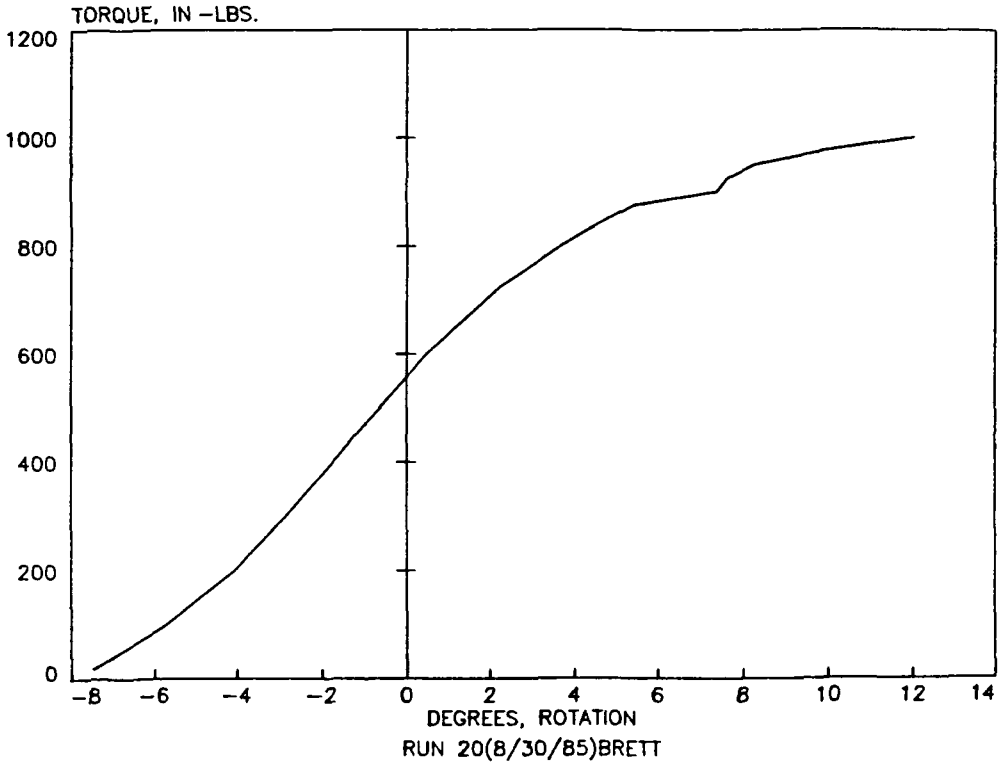
HEX BALL TORQUE TEST



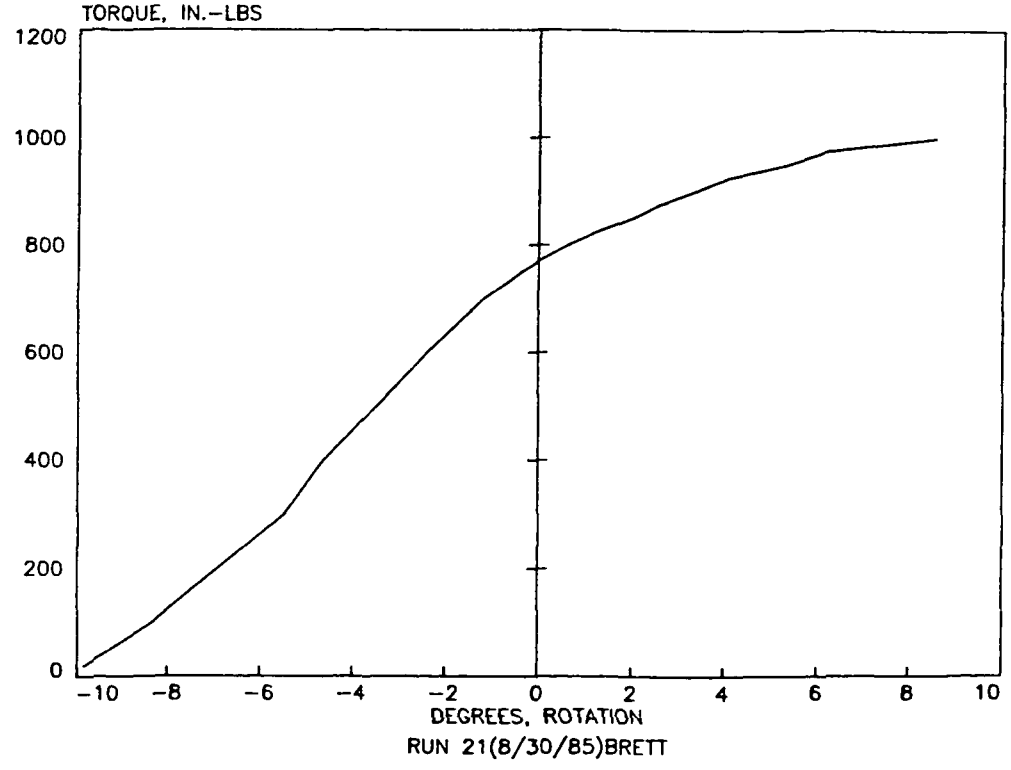
HEX BALL TORQUE TEST, RUN 19
FOR SPACE TELESCOPE



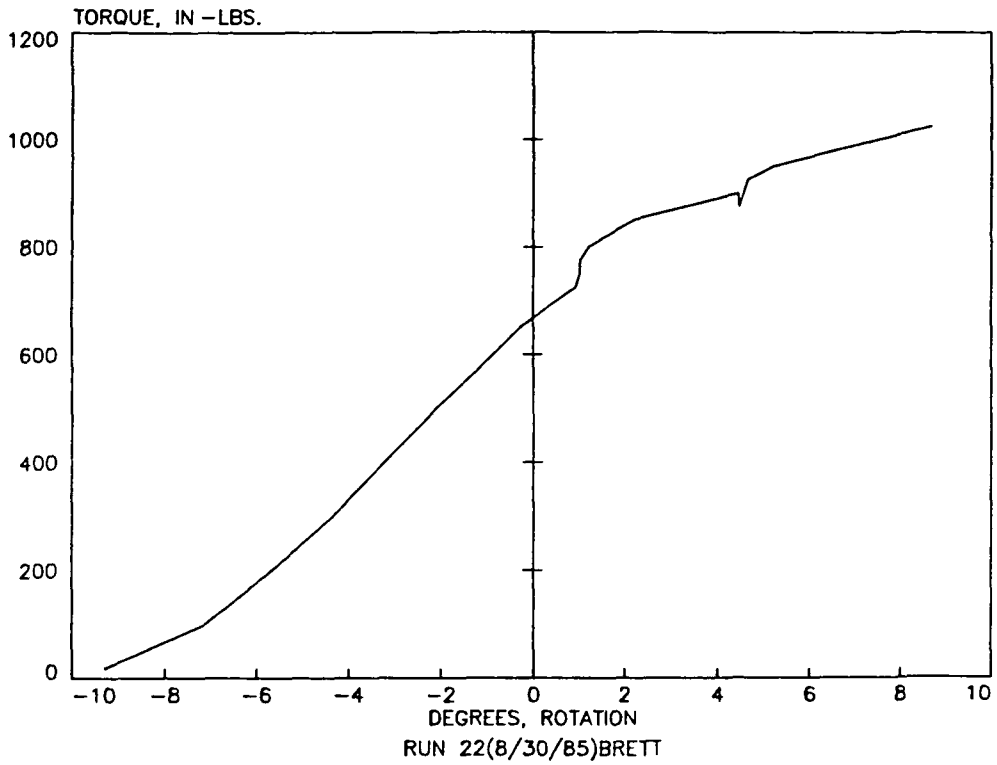
HEX BALL TORQUE TEST, RUN 20
FOR SPACE TELESCOPE



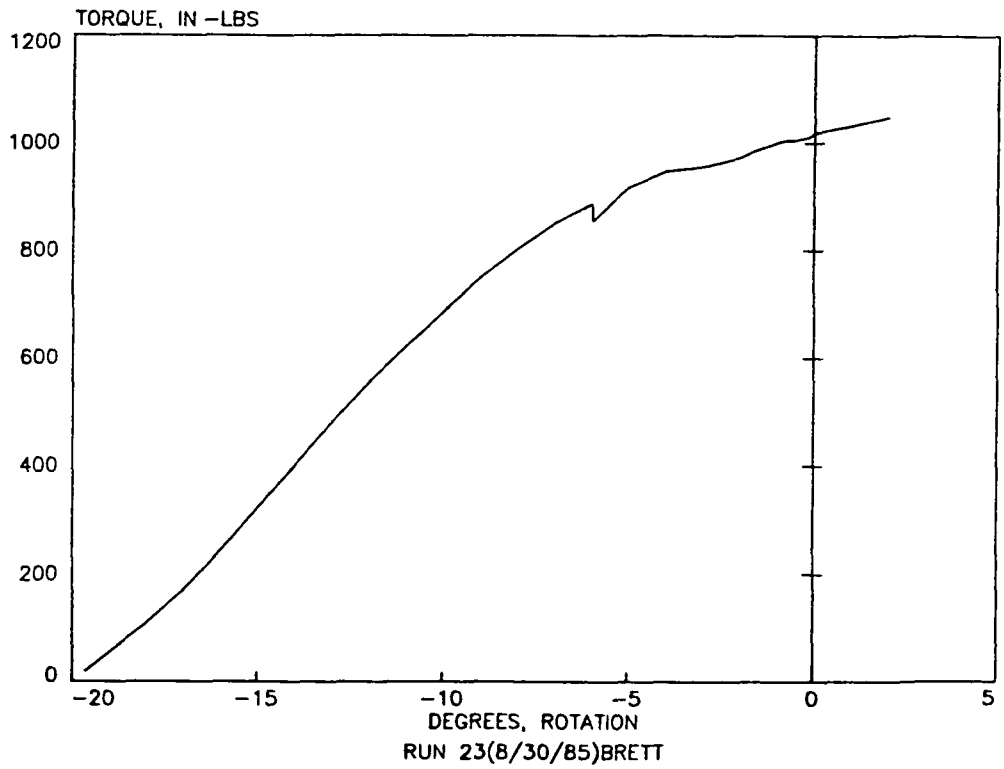
HEX BALL TORQUE TEST, RUN 21
FOR SPACE TELESCOPE



HEX BALL TORQUE TEST, RUN 22
FOR SPACE TELESCOPE



HEX BALL TORQUE TEST, RUN 23
FOR SPACE TELESCOPE



APPENDIX D

PRE- AND POST-TEST DIMENSIONAL MEASUREMENTS

FIGURE 1

Date 7-9-85
Hex Ball Specimen No. 1
Hex Ball Housing Specimen No. 1
Run No. 1

DIMENSION	PRE-TEST VALUE	POST-TEST VALUE
A	0.3743	0.3743
B	0.3742	0.3743
C	0.3200	0.3200
D (1 to 4)	0.3749	0.3750
E (2 to 5)	0.3749	0.3750
F (3 to 6)	0.3750	0.3750
G (1,2 to 5,4)	0.4298	0.4299
H (2,3 to 6,5)	0.4305	0.4305
I (3,4 to 1,6)	0.4295	0.4300
J	0.4206	0.4206
K	0.3745	0.3745
L (1 to 4)	0.3750	0.3750
M (2 to 5)	0.3750	0.3750
N (3 to 6)	0.3750	0.3750
O	0.3270	0.3275

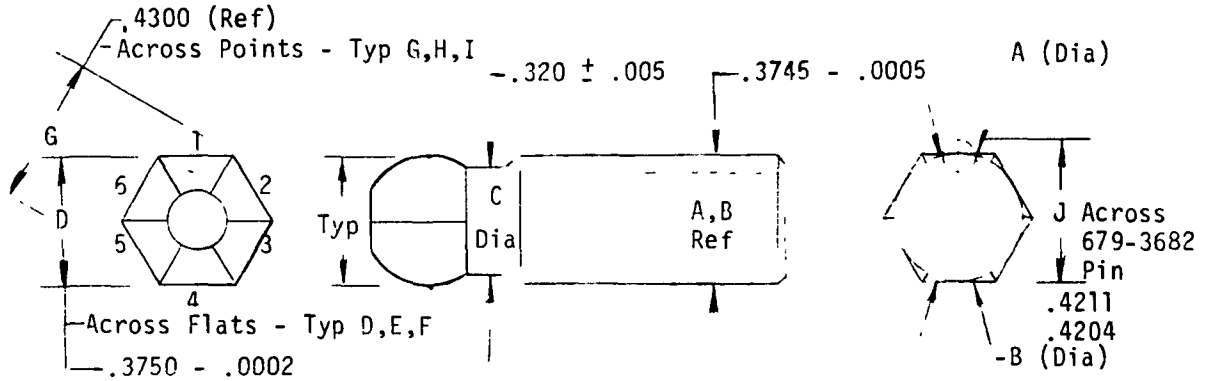
REMARKS (Visual Condition)

Dimensions K-L was measured with a digital caliper which was only accurate to three places.

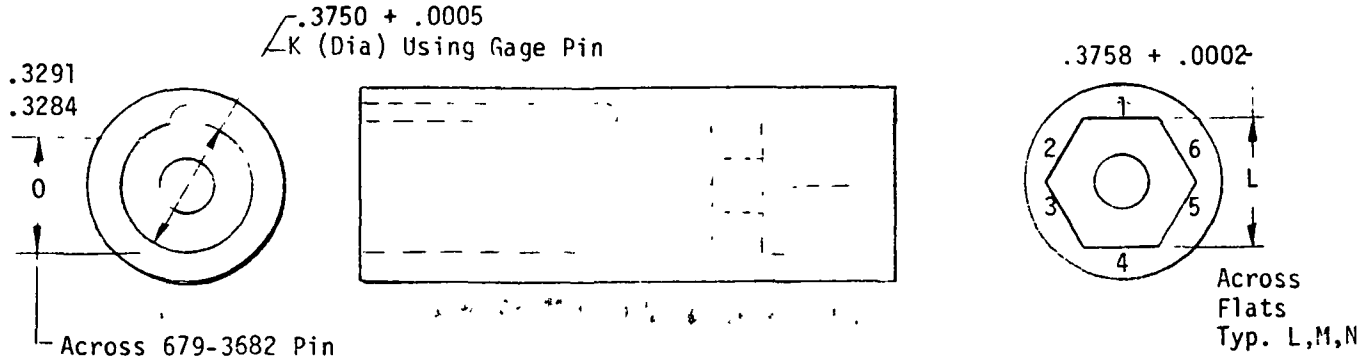
Slight abrasions around the edges of the hex head.

Dimension C was measured with a three place accuracy blade micrometer.

Load markings were visible on the post test hex head. The hex housing also had load markings.



Hex Ball 679-3628
B/P Dimensions & Tolerances
Shown for Reference



Hex Ball Housing 679-3629
B/P Dimensions & Tolerances
shown for reference

FIGURE 1

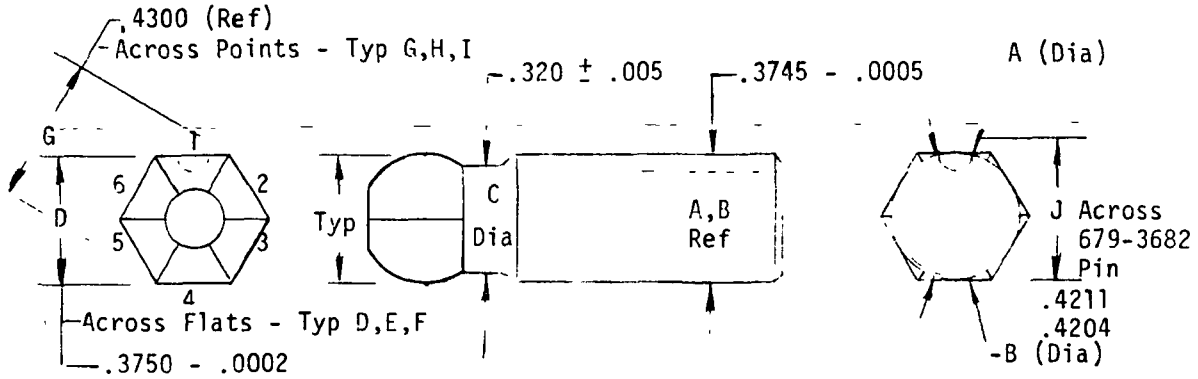
ORIGINAL PAGE IS
OF POOR QUALITY

Date 7/10/85
Hex Ball Specimen No. 1
Hex Ball Housing Specimen No. 1
Run No. 2

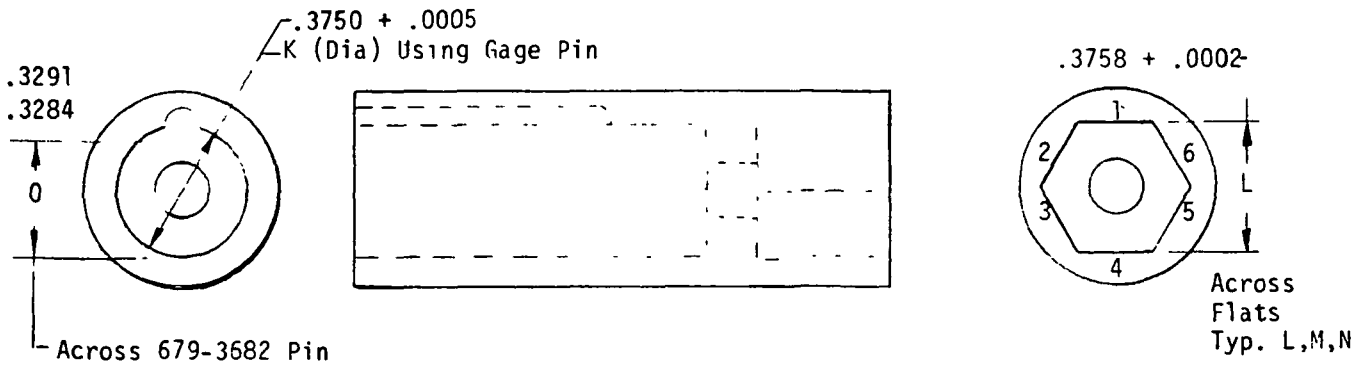
DIMENSION	PRE-TEST VALUE	POST-TEST VALUE
A	0.3743	0.3743
B	0.3743	0.3743
C	0.3200	0.3200
D (1 to 4)	0.3750	0.3750
E (2 to 5)	0.3750	0.3750
F (3 to 6)	0.3750	0.3750
G (1,2 to 5,4)	0.4299	0.4301
H (2,3 to 6,5)	0.4305	0.4305
I (3,4 to 1,6)	0.4300	0.4300
J	0.4206	0.4206
K	0.3745	0.3745
L (1 to 4)	0.3750	0.3750
M (2 to 5)	0.3750	0.3750
N (3 to 6)	0.3750	0.3750
O	0.3275	0.3275

REMARKS (Visual Condition)

Post Test: Load markings were approximately the same as previous run.



Hex Ball 679-3628
B/P Dimensions & Tolerances
Shown for Reference

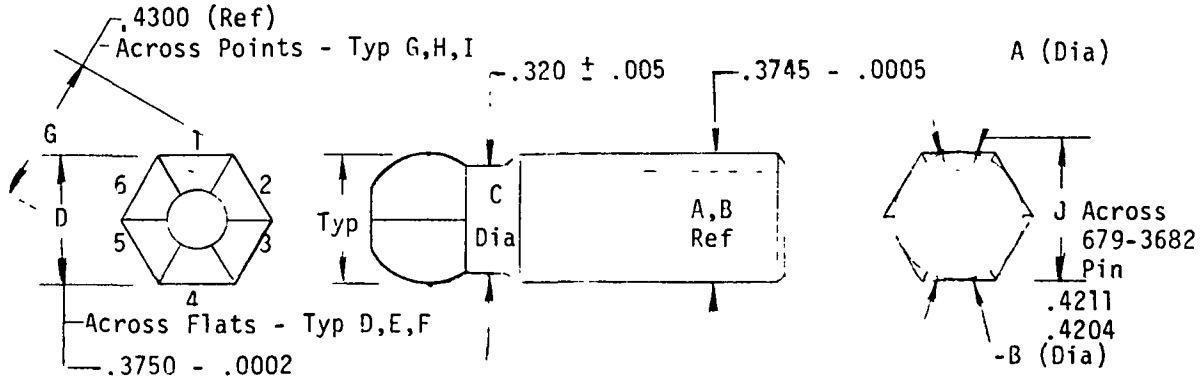


Hex Ball Housing 679-3629
B/P Dimensions & Tolerances
shown for reference

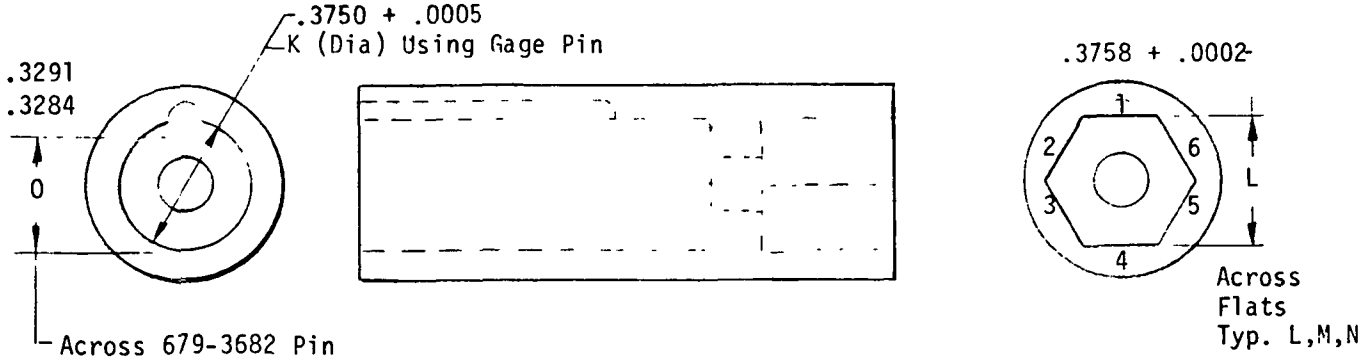
FIGURE 1

Date 8/27
Hex Ball Specimen No. 1
Hex Ball Housing Specimen No. 1
Run No. 2-A

DIMENSION	PRE-TEST VALUE	POST-TEST VALUE	REMARKS (Visual Condition)
A	0.3744	0.3744	
B	0.3744	0.3744	
C	0.3190	0.3190	
D (1 to 4)	0.3750	0.3750	
E (2 to 5)	0.3750	0.3750	
F (3 to 6)	0.3751	0.3751	
G (1,2 to 5,4)	0.4300	0.4300	
H (2,3 to 6,5)	0.4304	0.4304	
I (3,4 to 1,6)	0.4300	0.4300	
J	0.4205	0.4205	
K	0.3740	0.3740	
L (1 to 4)	0.3750	0.3750	
M (2 to 5)	0.3745	0.3745	
N (3 to 6)	0.3745	0.3745	
O	0.3285	0.3285	



Hex Ball 679-3628
B/P Dimensions & Tolerances
Shown for Reference



Hex Ball Housing 679-3629
B/P Dimensions & Tolerances
shown for reference

FIGURE 1

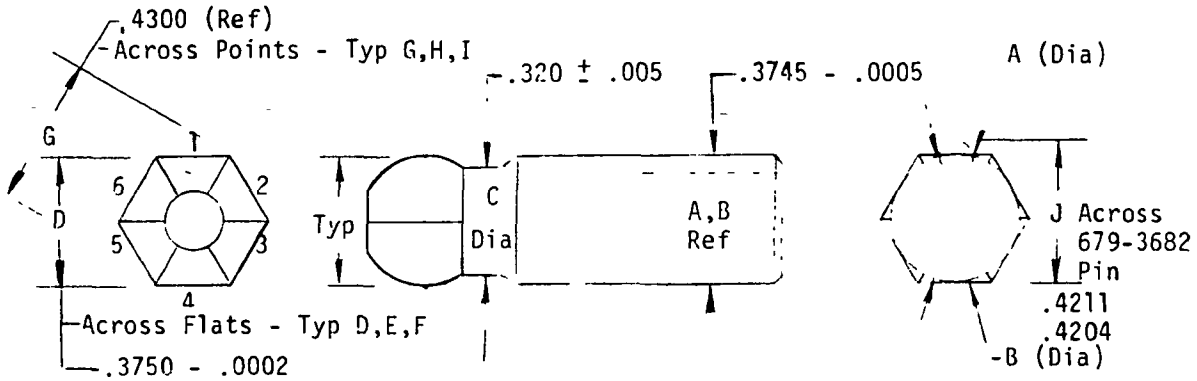
Date 7/11/85
Hex Ball Specimen No. 2
Hex Ball Housing Specimen No. 2
Run No. 3

DIMENSION	PRE-TEST VALUE	POST-TEST VALUE
A	0.3745	0.3745
B	0.3744	0.3745
C	0.3190	0.3190
D (1 to 4)	0.3750	0.3752
E (2 to 5)	0.3750	0.3752
F (3 to 6)	0.3750	0.3753
G (1,2 to 5,4)	0.4308	0.4293
H (2,3 to 6,5)	0.4309	0.4135
I (3,4 to 1,6)	0.4305	0.4314
J	0.4210	0.4208
K	0.3750	0.3735
L (1 to 4)	0.3760	0.3750
M (2 to 5)	0.3750	0.3750
N (3 to 6)	0.3755	0.3750
O	0.3270	0.3280

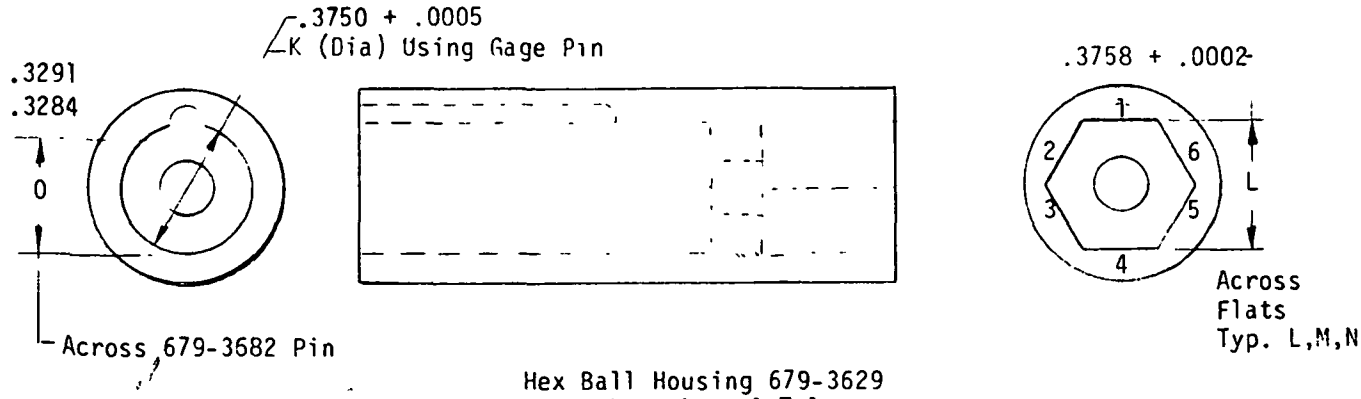
REMARKS (Visual Condition)

Dimension C was measured with a three place accuracy blade micrometer.

Slight scratches around hex edge of hex ball housing.



Hex Ball 679-3628
B/P Dimensions & Tolerances
Shown for Reference



Hex Ball Housing 679-3629
B/P Dimensions & Tolerances
shown for reference

FIGURE 1

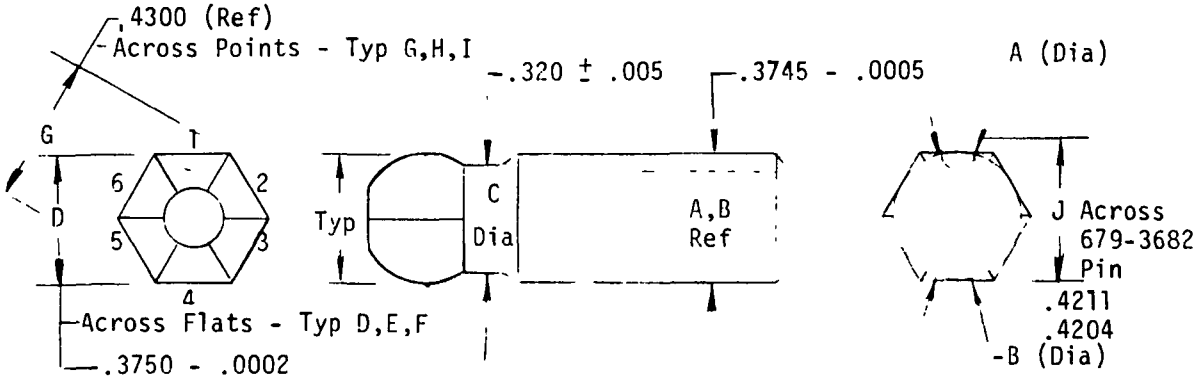
Date 8/27
Hex Ball Specimen No. 2
Hex Ball Housing Specimen No. 2
Run No. 4

DIMENSION	PRE-TEST VALUE	POST-TEST VALUE
A	0.3745	0.3746
B	0.3745	0.3746
C	0.3190	0.3190
D (1 to 4)	0.3752	0.3751
E (2 to 5)	0.3752	0.3750
F (3 to 6)	0.3753	0.3750
G (1,2 to 5,4)	0.4295	0.4279
H (2,3 to 6,5)	0.4135	0.4280
I (3,4 to 1,6)	0.4304	0.4278
J	0.4208	0.4211
K	0.3735	0.3745
L (1 to 4)	0.3750	0.3745
M (2 to 5)	0.3750	0.3750
N (3 to 6)	0.3750	0.3750
O	0.3280	0.3280

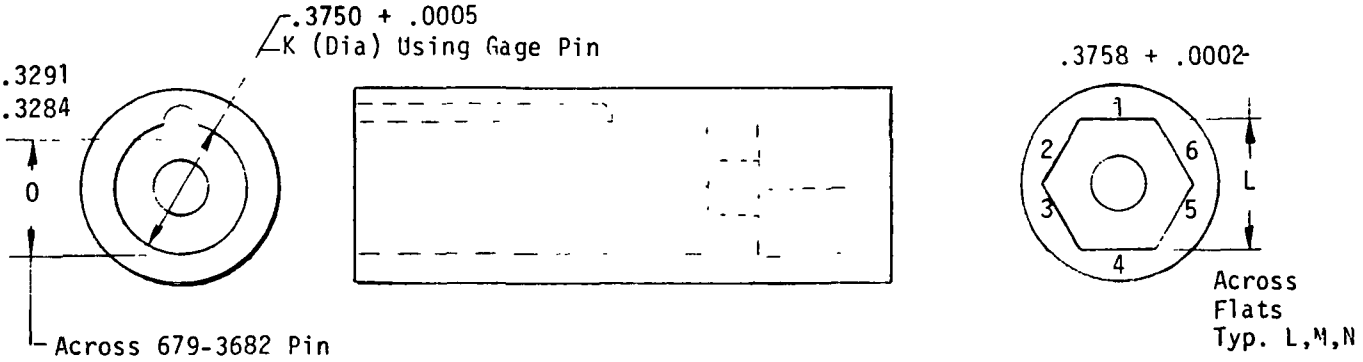
REMARKS (Visual Condition)

The corners of the hex ball show more signs of wear.

Slight burnishing, more metallic flakes came out upon separation.



Hex Ball 679-3628
B/P Dimensions & Tolerances
Shown for Reference

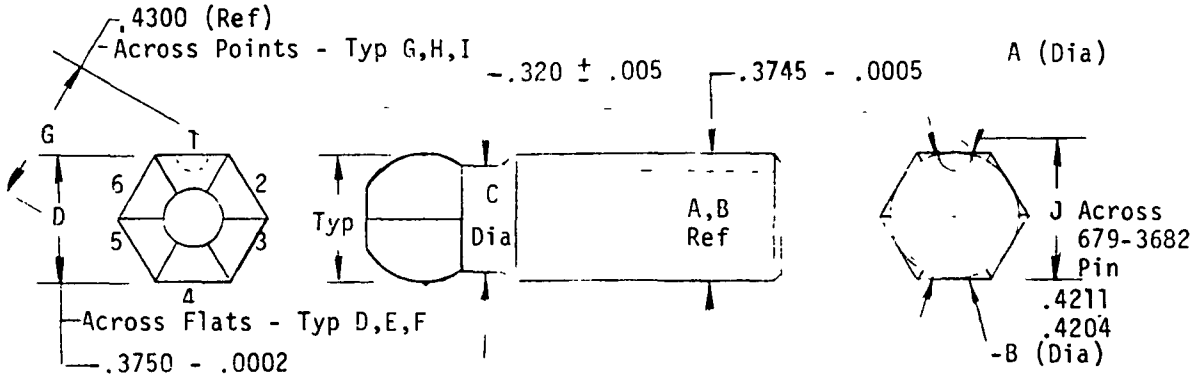


Hex Ball Housing 679-3629
B/P Dimensions & Tolerances
shown for reference

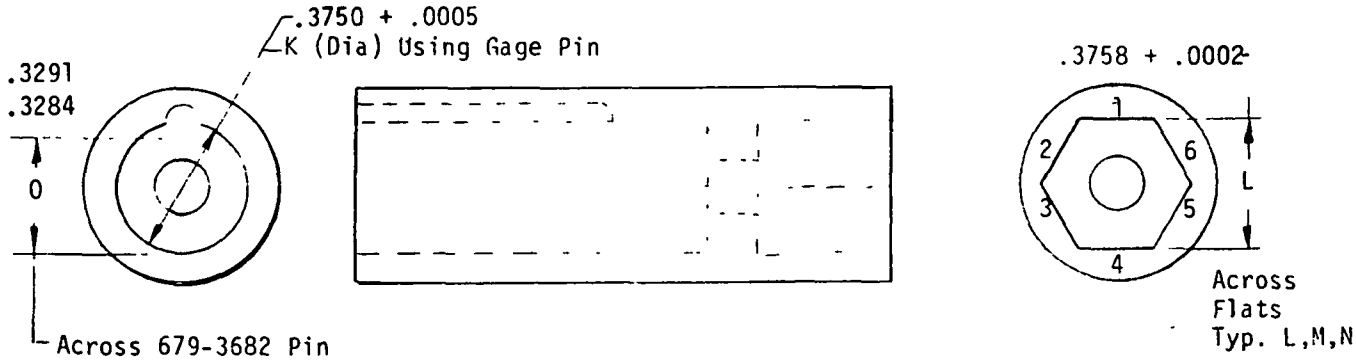
FIGURE 1

Date 8/27
Hex Ball Specimen No. 2
Hex Ball Housing Specimen No. 2
Run No. 5

DIMENSION	PRE-TEST VALUE	POST-TEST VALUE	REMARKS (Visual Condition)
A	0.3746	0.3745	
B	0.3746	0.3745	
C	0.3190	0.3190	
D (1 to 4)	0.3751	0.3751	
E (2 to 5)	0.3750	0.3749	
F (3 to 6)	0.3750	0.3750	
G (1,2 to 5,4)	0.4279	0.4279	
H (2,3 to 6,5)	0.4280	0.4280	
I (3,4 to 1,6)	0.4278	0.4276	
J	0.4211	0.4210	
K	0.3745	0.3740	
L (1 to 4)	0.3745	0.3745	
M (2 to 5)	0.3750	0.3750	
N (3 to 6)	0.3750	0.3750	
O	0.3280	0.3285	



Hex Ball 679-3628
B/P Dimensions & Tolerances
Shown for Reference

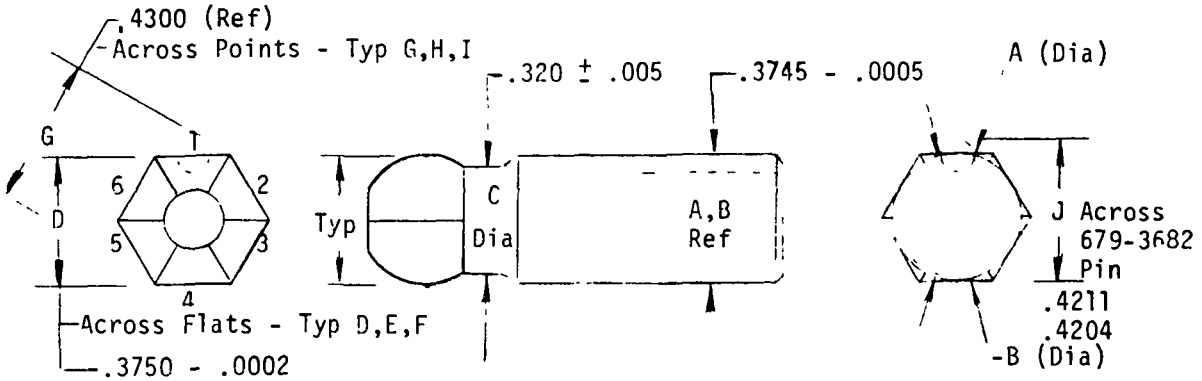


Hex Ball Housing 679-3629
B/P Dimensions & Tolerances
shown for reference

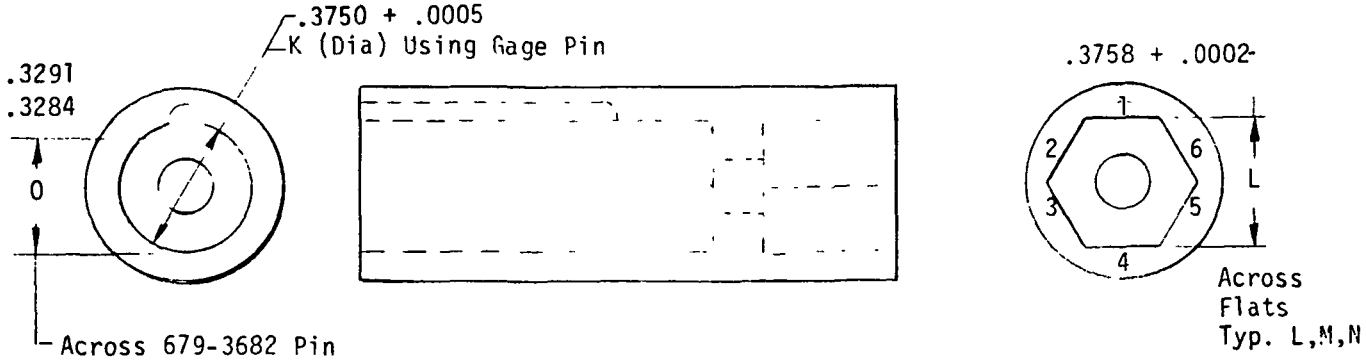
FIGURE 1

Date 8/27
Hex Ball Specimen No. 2
Hex Ball Housing Specimen No. 2
Run No. 6

DIMENSION	PRE-TEST VALUE	POST-TEST VALUE	REMARKS (Visual Condition)
A	0.3745	0.3745	Hex ball visually shows very little change.
B	0.3745	0.3745	
C	0.3190	0.3190	
D (1 to 4)	0.3751	0.3750	
E (2 to 5)	0.3749	0.3750	
F (3 to 6)	0.3750	0.3749	
G (1,2 to 5,4)	0.4279	0.4282	
H (2,3 to 6,5)	0.4280	0.4280	
I (3,4 to 1,6)	0.4276	0.4280	
J	0.4210	0.4209	
K	0.3740	0.3745	
L (1 to 4)	0.3745	0.3745	
M (2 to 5)	0.3750	0.3750	
N (3 to 6)	0.3750	0.3750	
O	0.3285	0.3280	



Hex Ball 679-3628
B/P Dimensions & Tolerances
Shown for Reference

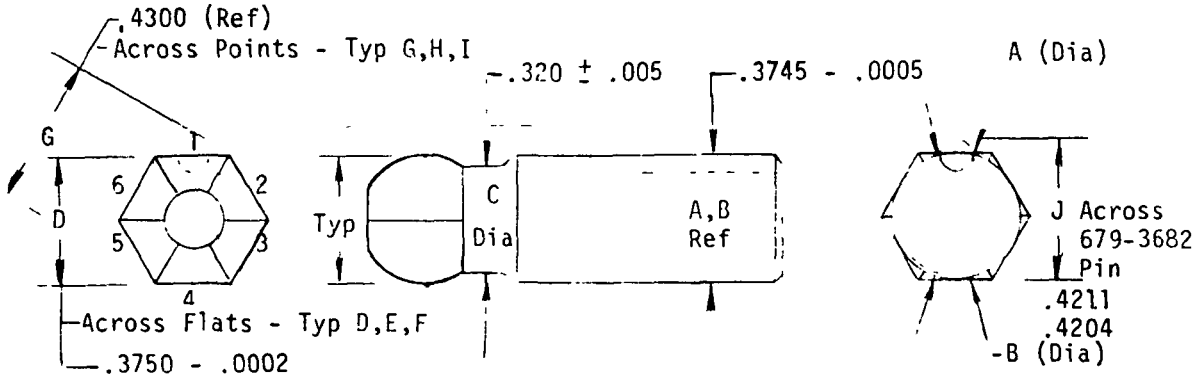


Hex Ball Housing 679-3629
B/P Dimensions & Tolerances
shown for reference

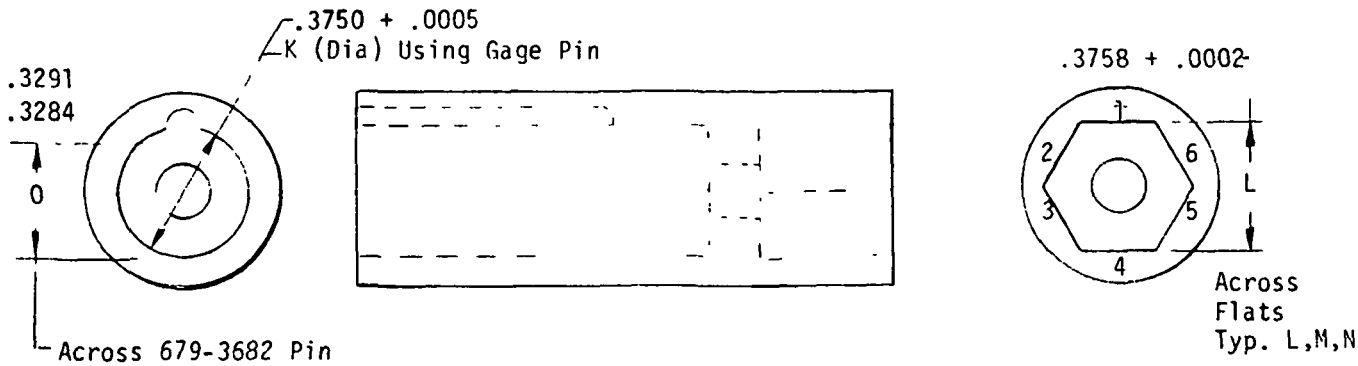
FIGURE 1

Date 8/27
Hex Ball Specimen No. 2
Hex Ball Housing Specimen No. 2
Run No. 7

DIMENSION	PRE-TEST VALUE	POST-TEST VALUE	REMARKS (Visual Condition)
A	0.3745	0.3746	Pretest and Post-test No change in visual appearance.
B	0.3745	0.3745	
C	0.3190	0.3190	
D (1 to 4)	0.3750	0.3751	
E (2 to 5)	0.3750	0.3749	
F (3 to 6)	0.3749	0.3749	
G (1,2 to 5,4)	0.4282	0.4283	
H (2,3 to 6,5)	0.4280	0.4281	
I (3,4 to 1,6)	0.4280	0.4280	
J	0.4209	0.4211	
K	0.3745	0.3745	
L (1 to 4)	0.3745	0.3750	
M (2 to 5)	0.3750	0.3750	
N (3 to 6)	0.3750	0.3750	
O	0.3280	0.3285	



Hex Ball 679-3628
B/P Dimensions & Tolerances
Shown for Reference

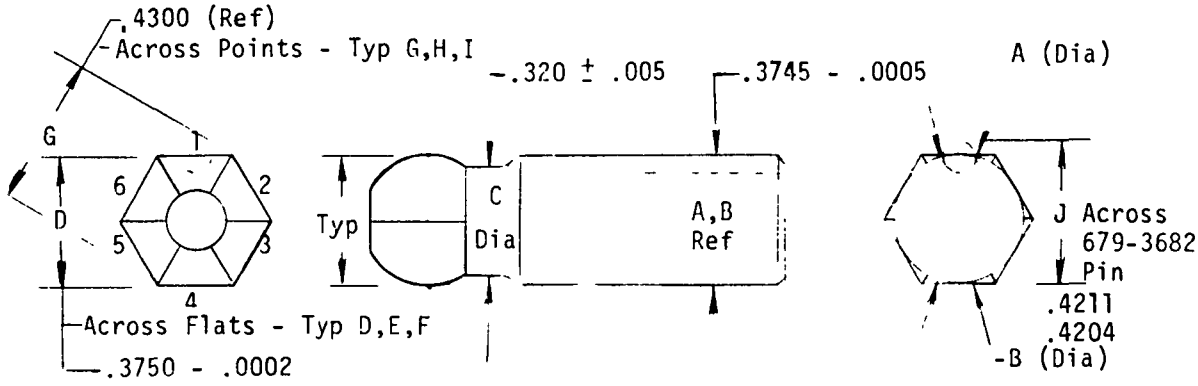


Hex Ball Housing 679-3629
B/P Dimensions & Tolerances
shown for reference

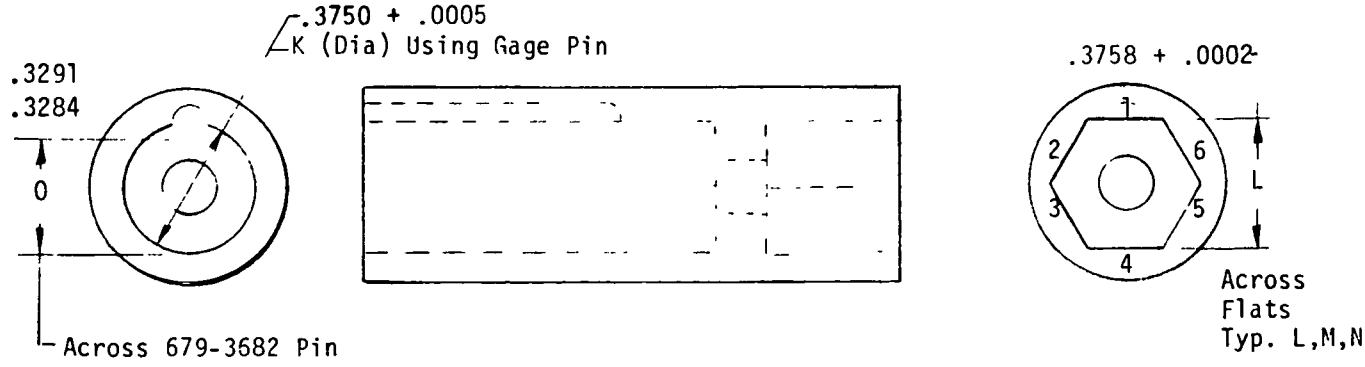
FIGURE 1

Date 8/28
Hex Ball Specimen No. 3
Hex Ball Housing Specimen No. 3
Run No. 8

DIMENSION	PRE-TEST VALUE	POST-TEST VALUE	REMARKS (Visual Condition)
A	0.3744	0.3744	Pre-test: No anomalies.
B	0.3744	0.3744	
C	0.3200	0.3200	
D (1 to 4)	0.3749	0.3750	
E (2 to 5)	0.3750	0.3750	
F (3 to 6)	0.3750	0.3750	
G (1,2 to 5,4)	0.4290	0.4295	
H (2,3 to 6,5)	0.4294	0.4300	
I (3,4 to 1,6)	0.4295	0.4300	
J	0.4207	0.4207	
K	0.3750	0.3745	
L (1 to 4)	0.3750	0.3750	
M (2 to 5)	0.3750	0.3750	
N (3 to 6)	0.3750	0.3750	
O	0.3280	0.3280	



Hex Ball 679-3628
B/P Dimensions & Tolerances
Shown for Reference

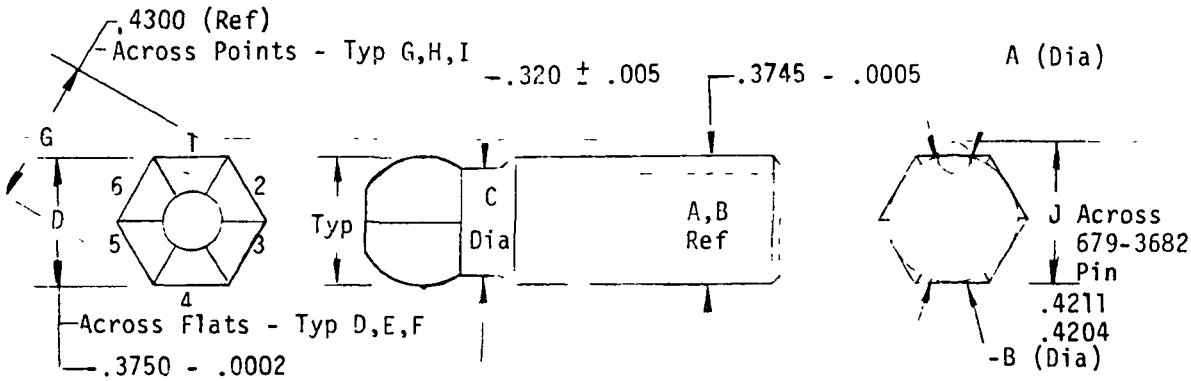


Hex Ball Housing 679-3629
B/P Dimensions & Tolerances
shown for reference

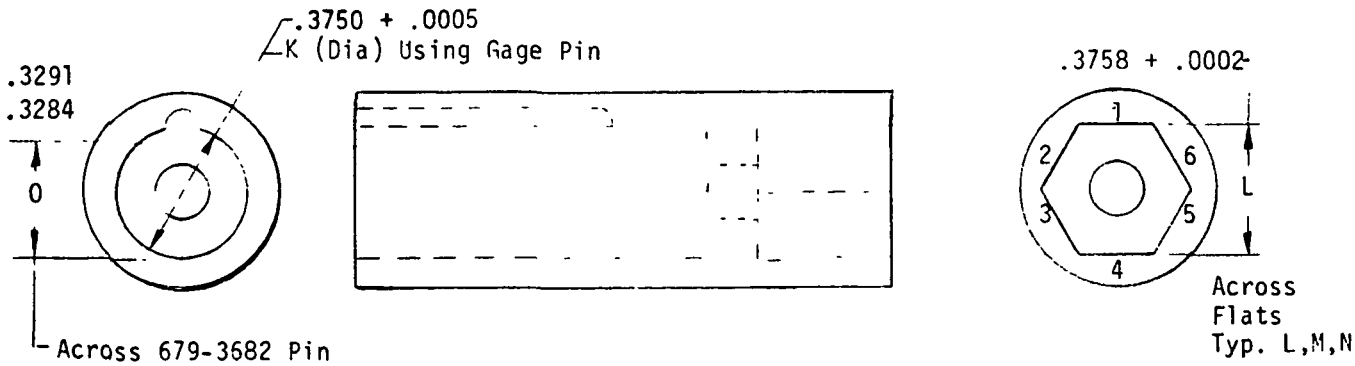
FIGURE 1

Date 8/28
Hex Ball Specimen No. 3
Hex Ball Housing Specimen No. 3
Run No. 9

DIMENSION	PRE-TEST VALUE	POST-TEST VALUE	REMARKS (Visual Condition)
A	0.3744	0.3743	There was no change.
B	0.3744	0.3743	
C	0.3200	0.3200	
D (1 to 4)	0.3750	0.3752	
E (2 to 5)	0.3750	0.3751	
F (3 to 6)	0.3750	0.3752	
G (1,2 to 5,4)	0.4295	0.4298	
H (2,3 to 6,5)	0.4300	0.4300	
I (3,4 to 1,6)	0.4300	0.4302	
J	0.4207	0.4206	
K	0.3745	0.3750	
L (1 to 4)	0.3750	0.3750	
M (2 to 5)	0.3750	0.3750	
N (3 to 6)	0.3750	0.3750	
O	0.3280	0.3285	



Hex Ball 679-3628
B/P Dimensions & Tolerances
Shown for Reference



Hex Ball Housing 679-3629
B/P Dimensions & Tolerances
shown for reference

FIGURE 1

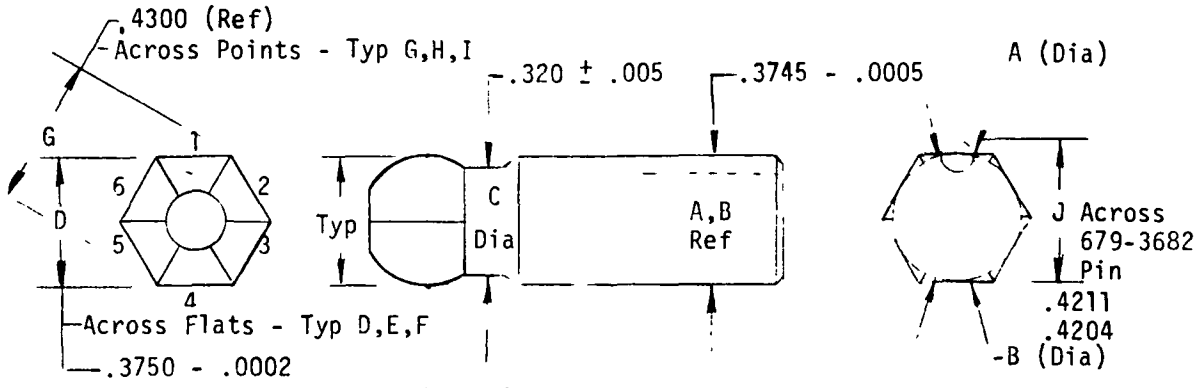
Date 8/28
Hex Ball Specimen No. 4
Hex Ball Housing Specimen No. 4
Run No. 10

DIMENSION	PRE-TEST VALUE	POST-TEST VALUE
A	0.3742	0.3744
B	0.3745	0.3747
C	0.3210	0.3210
D (1 to 4)	0.3749	0.3748
E (2 to 5)	0.3748	0.3746
F (3 to 6)	0.3749	0.3749
G (1,2 to 5,4)	0.4301	0.4302
H (2,3 to 6,5)	0.4302	0.4300
I (3,4 to 1,6)	0.4303	0.4300
J	0.4207	0.4208
K	0.3750	0.3750
L (1 to 4)	0.3750	0.3755
M (2 to 5)	0.3755	0.3750
N (3 to 6)	0.3755	0.3755
O	0.3280	0.3280

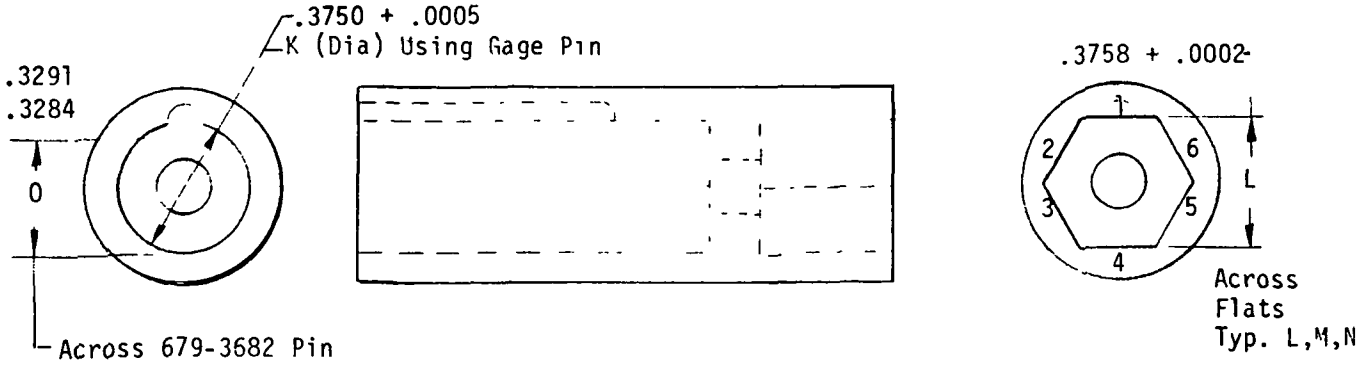
REMARKS (Visual Condition)

Pre-test: No anomalies.

Post-test: Hex ball corners are burnished and housing also shows signs of wear.



Hex Ball 679-3628
B/P Dimensions & Tolerances
Shown for Reference



Hex Ball Housing 679-3629
B/P Dimensions & Tolerances
shown for reference

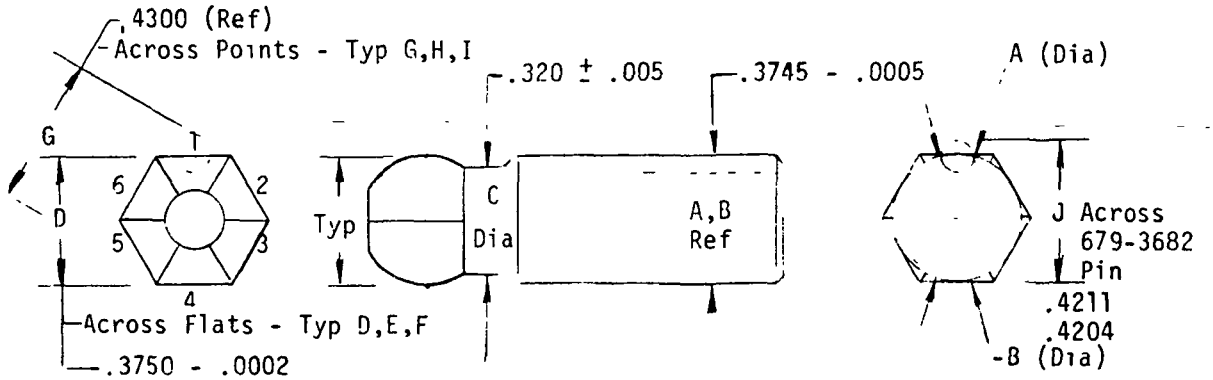
FIGURE 1

Date 8/28
Hex Ball Specimen No. 4
Hex Ball Housing Specimen No. 4
Run No. 11

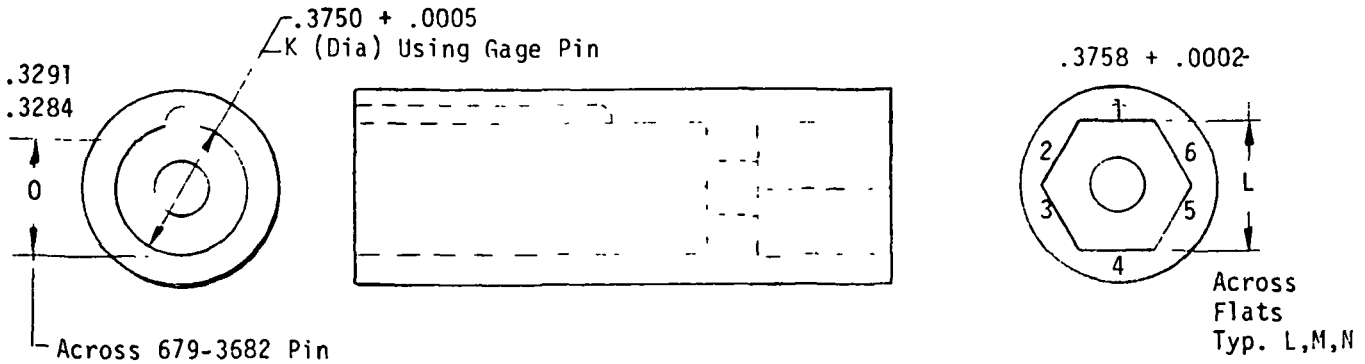
DIMENSION	PRE-TEST VALUE	POST-TEST VALUE
A	0.3744	0.3745
B	0.3747	0.3745
C	0.3210	0.3210
D (1 to 4)	0.3748	0.3747
E (2 to 5)	0.3746	0.3744
F (3 to 6)	0.3749	0.3746
G (1,2 to 5,4)	0.4302	0.4300
H (2,3 to 6,5)	0.4300	0.4298
I (3,4 to 1,6)	0.4300	0.4300
J	0.4208	0.4208
K	0.3750	0.3750
L (1 to 4)	0.3755	0.3755
M (2 to 5)	0.3750	0.3750
N (3 to 6)	0.3755	0.3750
O	0.3280	0.3280

REMARKS (Visual Condition)

Hex ball shows very slight, smooth wear on corners. The housing shows very slight signs of further wear.



Hex Ball 679-3628
B/P Dimensions & Tolerances
Shown for Reference

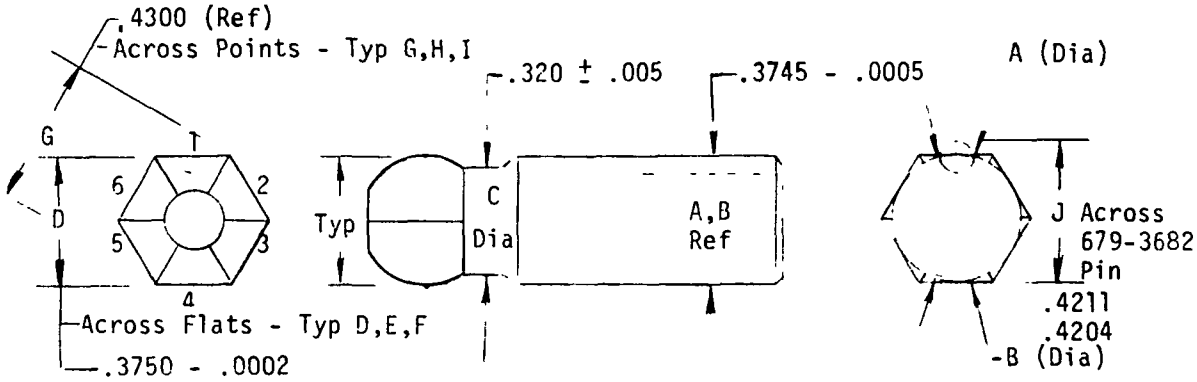


Hex Ball Housing 679-3629
B/P Dimensions & Tolerances
shown for reference

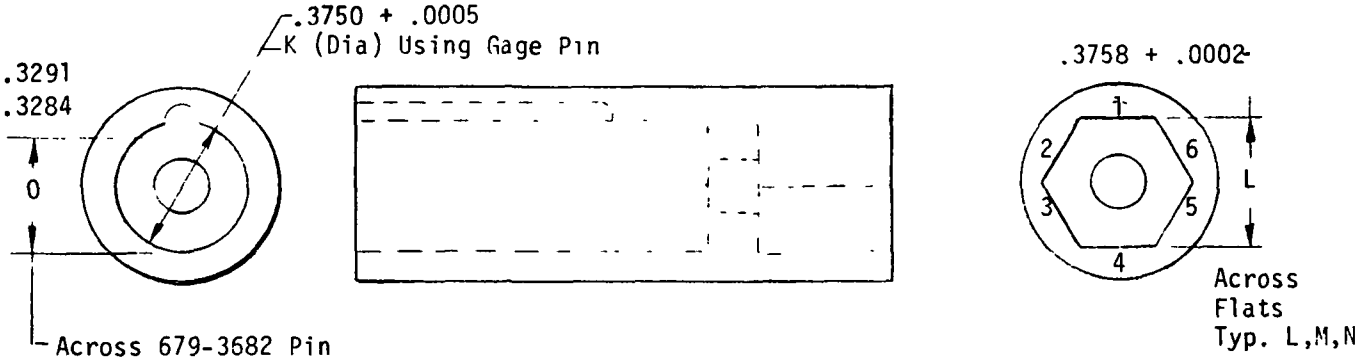
FIGURE 1

Date 8/28
Hex Ball Specimen No. 4
Hex Ball Housing Specimen No. 4
Run No. 12

DIMENSION	PRE-TEST VALUE	POST-TEST VALUE	REMARKS (Visual Condition)
A	0.3745	0.3744	No signs of further wear.
B	0.3745	0.3745	
C	0.3210	0.3210	
D (1 to 4)	0.3747	0.3747	
E (2 to 5)	0.3744	0.3746	
F (3 to 6)	0.3746	0.3747	
G (1,2 to 5,4)	0.4300	0.4298	
H (2,3 to 6,5)	0.4298	0.4300	
I (3,4 to 1,6)	0.4300	0.4300	
J	0.4208	0.4209	
K	0.3750	0.3750	
L (1 to 4)	0.3755	0.3755	
M (2 to 5)	0.3750	0.3755	
N (3 to 6)	0.3750	0.3750	
O	0.3280	0.3280	



Hex Ball 679-3628
B/P Dimensions & Tolerances
Shown for Reference

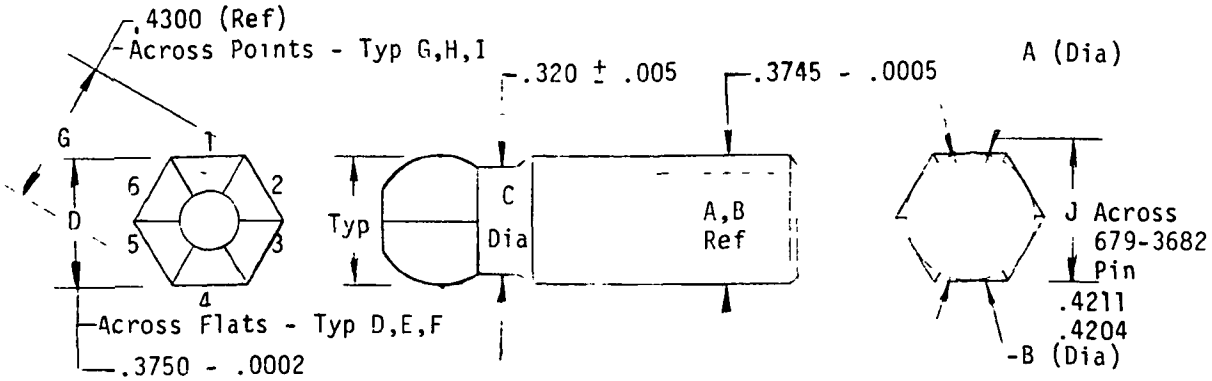


Hex Ball Housing 679-3629
B/P Dimensions & Tolerances
shown for reference

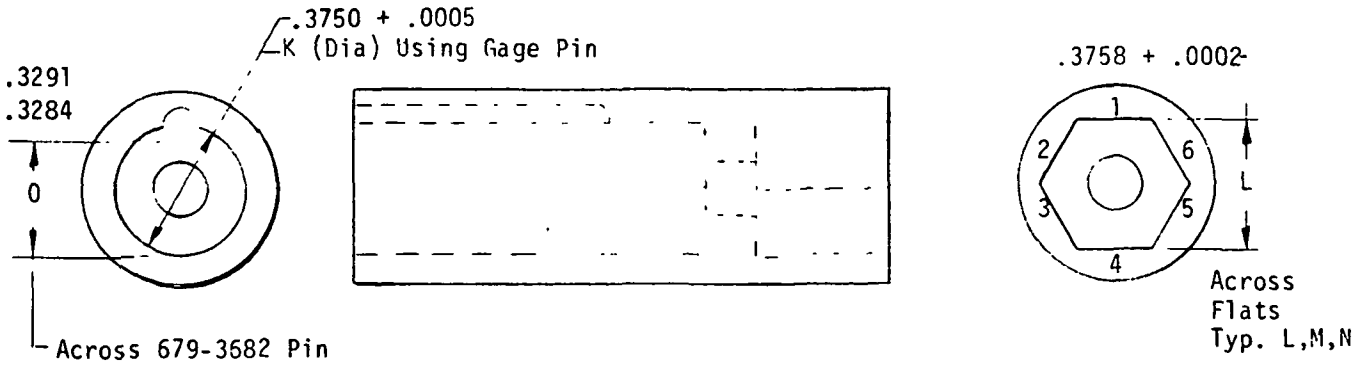
FIGURE 1

Date 8/29
Hex Ball Specimen No. 4
Hex Ball Housing Specimen No. 4
Run No. 13

DIMENSION	PRE-TEST VALUE	POST-TEST VALUE	REMARKS (Visual Condition)
A	0.3744	0.3745	No further signs of wear.
B	0.3745	0.3745	
C	0.3210	0.3210	
D (1 to 4)	0.3747	0.3748	
E (2 to 5)	0.3746	0.3744	
F (3 to 6)	0.3247	0.3746	
G (1,2 to 5,4)	0.4298	0.4298	
H (2,3 to 6,5)	0.4300	0.4300	
I (3,4 to 1,6)	0.4300	0.4299	
J	0.4209	0.4208	
K	0.3750	0.3750	
L (1 to 4)	0.3755	0.3755	
M (2 to 5)	0.3755	0.3750	
N (3 to 6)	0.3750	0.3750	
O	0.3280	0.3280	



Hex Ball 679-3628
B/P Dimensions & Tolerances
Shown for Reference

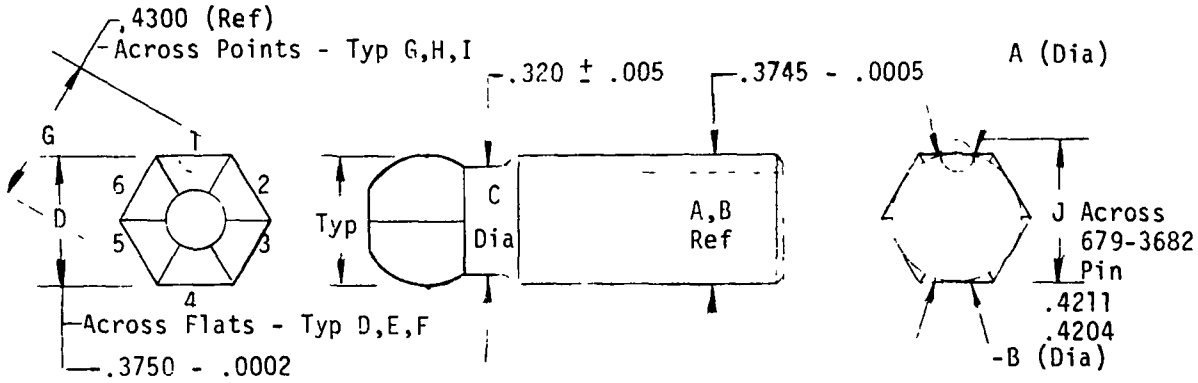


Hex Ball Housing 679-3629
B/P Dimensions & Tolerances
shown for reference

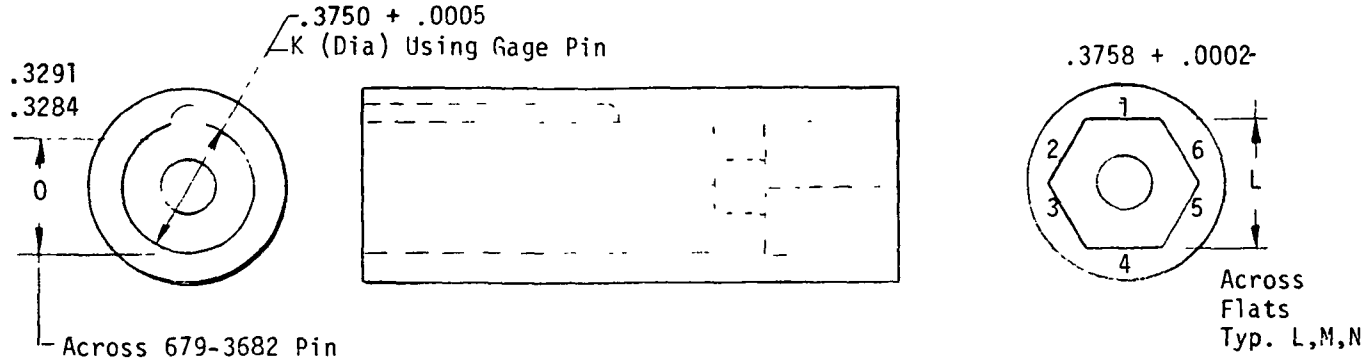
FIGURE 1

Date 8/29
Hex Ball Specimen No. 4
Hex Ball Housing Specimen No. 4
Run No. 14

DIMENSION	PRE-TEST VALUE	POST-TEST VALUE	REMARKS (Visual Condition)
A	0.3745	0.3745	Shows no signs of further wear.
B	0.3745	0.3745	
C	0.3210	0.3210	
D (1 to 4)	0.3748	0.3747	
E (2 to 5)	0.4744	0.3745	
F (3 to 6)	0.3746	0.3747	
G (1,2 to 5,4)	0.4298	0.4295	
H (2,3 to 6,5)	0.4300	0.4300	
I (3,4 to 1,6)	0.4299	0.4296	
J	0.4208	0.4209	
K	0.3750	0.3750	
L (1 to 4)	0.3755	0.3755	
M (2 to 5)	0.3750	0.3750	
N (3 to 6)	0.3750	0.3750	
O	0.3280	0.3275	



Hex Ball 679-3628
B/P Dimensions & Tolerances
Shown for Reference



Hex Ball Housing 679-3629
B/P Dimensions & Tolerances
shown for reference

C-2

FIGURE 1

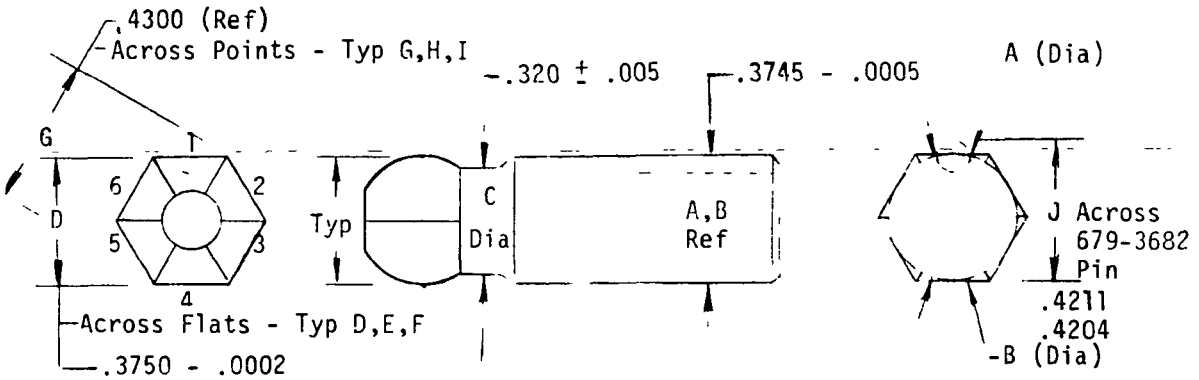
Date 7/30/85
Hex Ball Specimen No. 1
Hex Ball Housing Specimen No. 1
Run No. 15

ORIGINAL PAGE IS OF POOR QUALITY

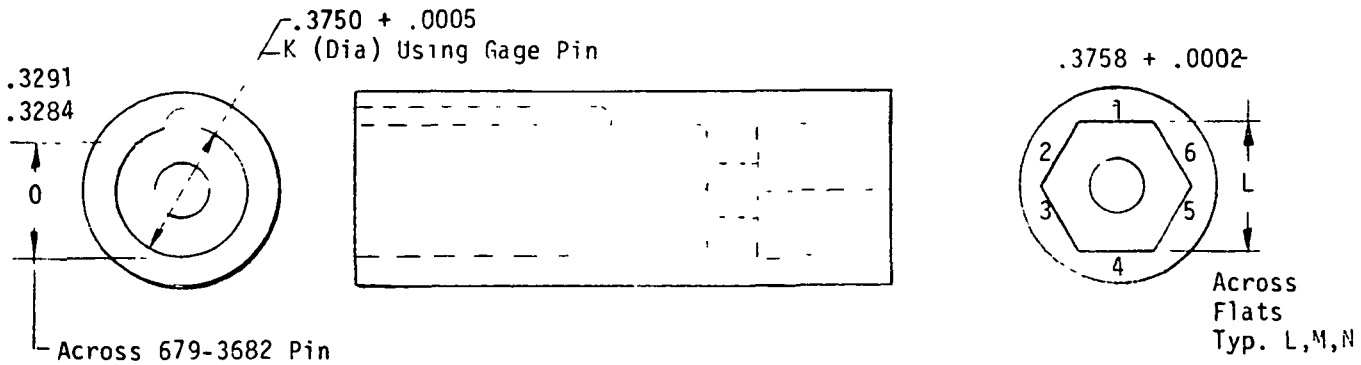
DIMENSION	PRE-TEST VALUE	POST-TEST VALUE
A	0.3744	0.3743
B	0.3744	0.3743
C	0.3190	0.3190
D (1 to 4)	0.3750	0.3753
E (2 to 5)	0.3750	0.3753
F (3 to 6)	0.3751	0.3753
G (1,2 to 5,4)	0.4300	0.4300
H (2,3 to 6,5)	0.4304	0.4304
I (3,4 to 1,6)	0.4300	0.4302
J	0.4205	0.4206
K	0.3740	0.3740
L (1 to 4)	0.3750	0.3750
M (2 to 5)	0.3745	0.3750
N (3 to 6)	0.3745	0.3745
O	0.3285	0.3285

REMARKS (Visual Condition)

Hex ball does not visually show any massive signs of yielding. Burnished edges on ball. Burnished corners on housing.



Hex Ball 679-3628
B/P Dimensions & Tolerances
Shown for Reference



Hex Ball Housing 679-3629
B/P Dimensions & Tolerances
shown for reference

FIGURE 1

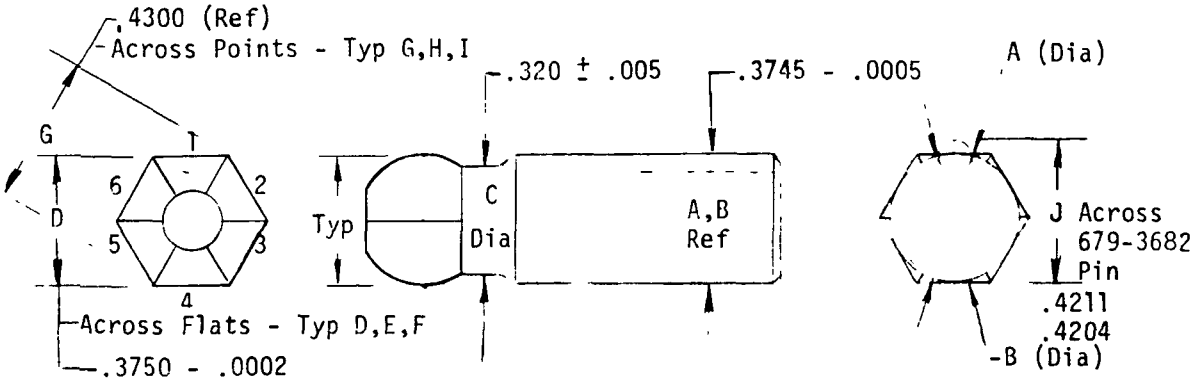
Date 8/29
Hex Ball Specimen No. 2
Hex Ball Housing Specimen No. 2
Run No. 16

DIMENSION	PRE-TEST VALUE	POST-TEST VALUE
A	0.3746	0.3746
B	0.3745	0.3746
C	0.3190	0.3190
D (1 to 4)	0.3751	0.3750
E (2 to 5)	0.3749	0.3750
F (3 to 6)	0.3749	0.3748
G (1,2 to 5,4)	0.4283	0.4283
H (2,3 to 6,5)	0.4381	0.4282
I (3,4 to 1,6)	0.4280	0.4278
J	0.4211	0.4210
K	0.3745	0.3750
L (1 to 4)	0.3750	0.3750
M (2 to 5)	0.3750	0.3750
N (3 to 6)	0.3750	0.3750
O	0.3285	0.3285

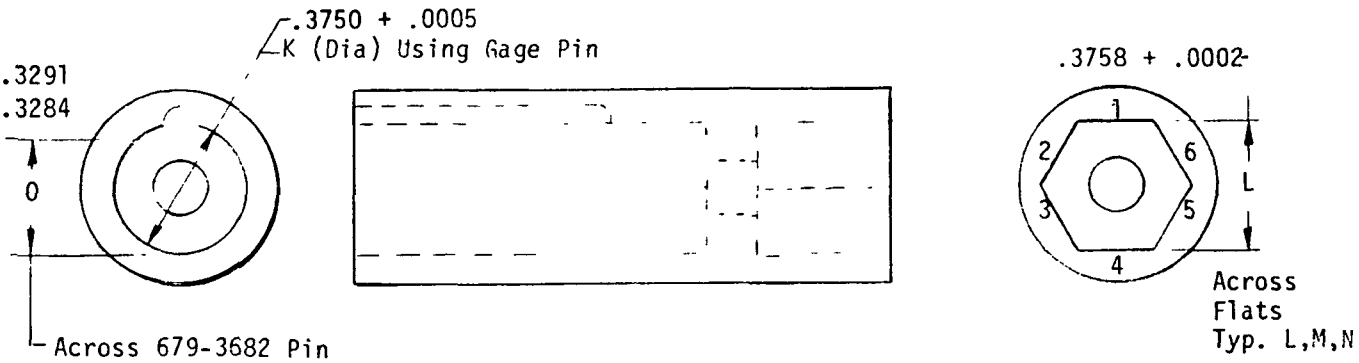
REMARKS (Visual Condition)

Hex is worn from initial durability torque test.

Post Yield: Hex looks twisted and shows extra signs of wear for CW load.



Hex Ball 679-3628
B/P Dimensions & Tolerances
Shown for Reference



Hex Ball Housing 679-3629
B/P Dimensions & Tolerances
shown for reference

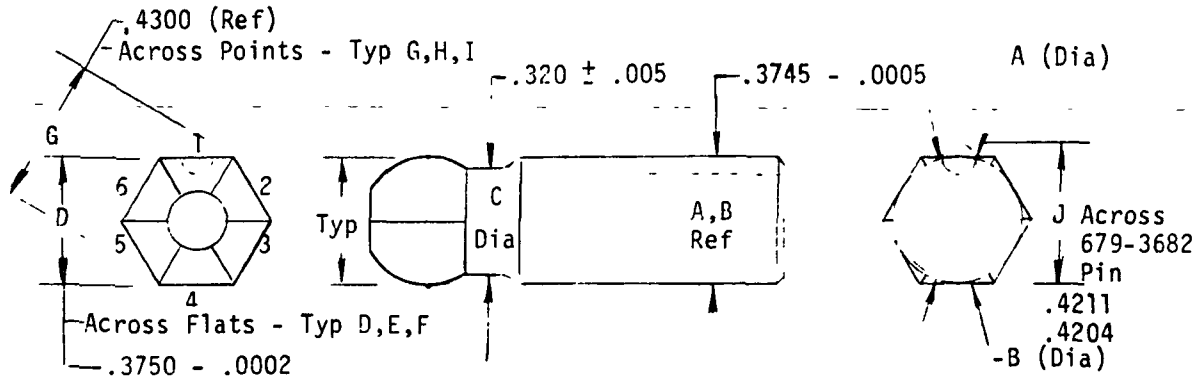
FIGURE 1

Date 8/29
Hex Ball Specimen No. 3
Hex Ball Housing Specimen No. 3
Run No. 17

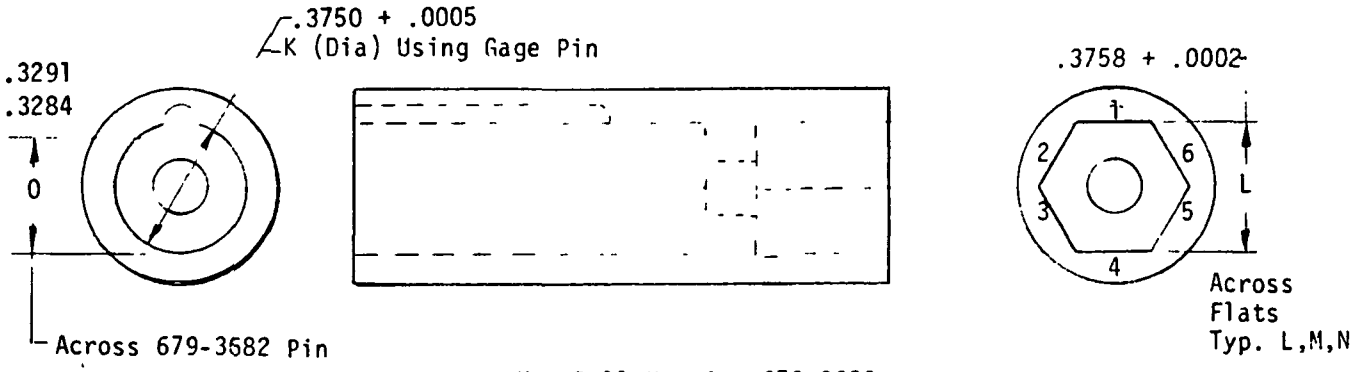
DIMENSION	PRE-TEST VALUE	POST-TEST VALUE
A	0.3743	0.3743
B	0.3743	0.3743
C	0.3200	0.3200
D (1 to 4)	0.3752	0.3757
E (2 to 5)	0.3751	0.3756
F (3 to 6)	0.3752	0.3758
G (1,2 to 5,4)	0.4298	0.4300
H (2,3 to 6,5)	0.4300	0.4300
I (3,4 to 1,6)	0.4302	0.4302
J	0.4206	0.4204
K	0.3750	0.3750
L (1 to 4)	0.3750	0.3750
M (2 to 5)	0.3750	0.3750
N (3 to 6)	0.3750	0.3750
O	0.3280	0.3280

REMARKS (Visual Condition)

Hex ball looks twisted and shows further signs of CW load.



Hex Ball 679-3628
B/P Dimensions & Tolerances
Shown for Reference

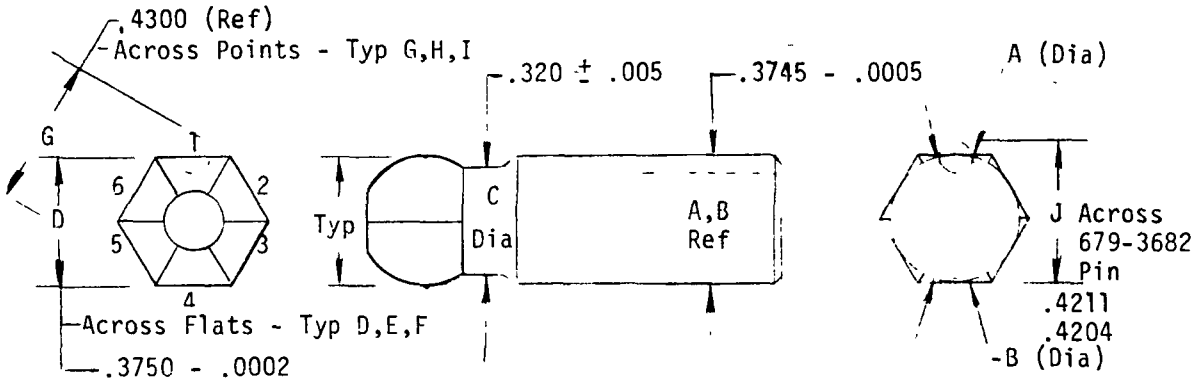


Hex Ball Housing 679-3629
B/P Dimensions & Tolerances
shown for reference

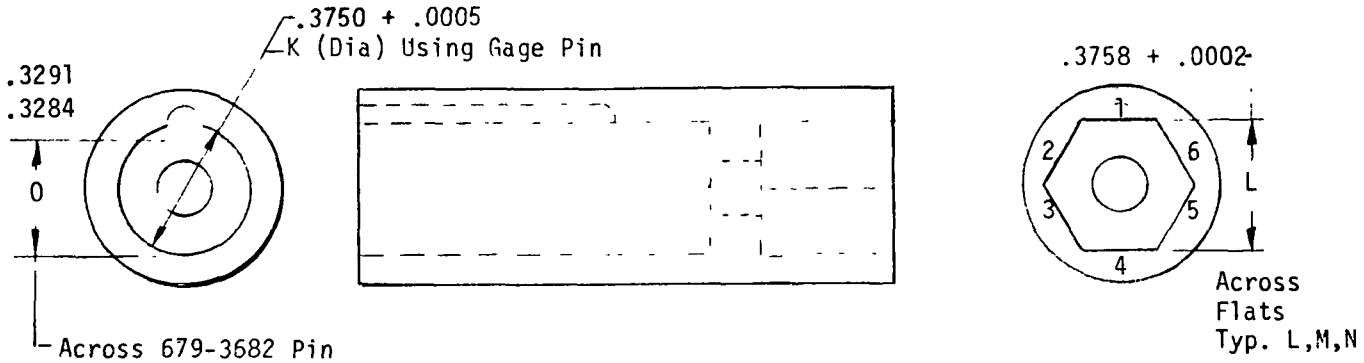
FIGURE 1

Date 8/29
Hex Ball Specimen No. 4
Hex Ball Housing Specimen No. 4
Run No. 18

DIMENSION	PRE-TEST VALUE	POST-TEST VALUE	REMARKS (Visual Condition)
A	0.3745	0.3745	
B	0.3745	0.3744	
C	0.3210	0.3210	
D (1 to 4)	0.3747	0.3753	
E (2 to 5)	0.3745	0.3752	
F (3 to 6)	0.3747	0.3754	
G (1,2 to 5,4)	0.4295	0.4300	
H (2,3 to 6,5)	0.4300	0.4300	
I (3,4 to 1,6)	0.4296	0.4300	
J	0.4209	0.4211	
K	0.3750	0.3745	
L (1 to 4)	0.3755	0.3755	
M (2 to 5)	0.3750	0.3755	
N (3 to 6)	0.3750	0.3755	
O	0.3275	0.3280	



Hex Ball 679-3628
B/P Dimensions & Tolerances
Shown for Reference



Hex Ball Housing 679-3629
B/P Dimensions & Tolerances
shown for reference

FIGURE 1

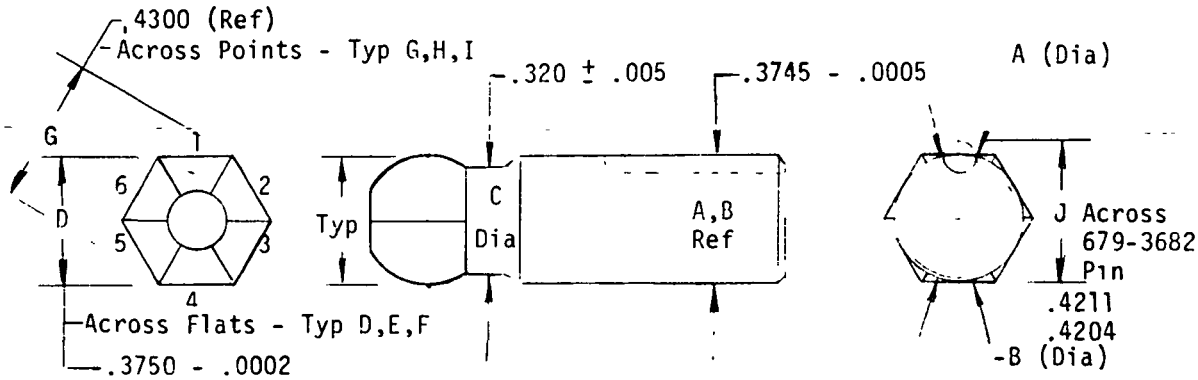
Date 8/29
Hex Ball Specimen No. 1
Hex Ball Housing Specimen No. 1
Run No. 19

DIMENSION	PRE-TEST VALUE	POST-TEST VALUE
A	0.3743	0.3788*
B	0.3743	0.3742
C	0.3190	0.3190
D (1 to 4)	0.3753	0.3758
E (2 to 5)	0.3753	0.3758
F (3 to 6)	0.3753	0.3757
G (1,2 to 5,4)	0.4300	0.4300
H (2,3 to 6,5)	0.4304	0.4298
I (3,4 to 1,6)	0.4302	0.4300
J	0.4206	0.4206
K	0.3740	0.3740
L (1 to 4)	0.3750	0.3750
M (2 to 5)	0.3750	0.3750
N (3 to 6)	0.3745	0.3750
O	0.3285	0.3270

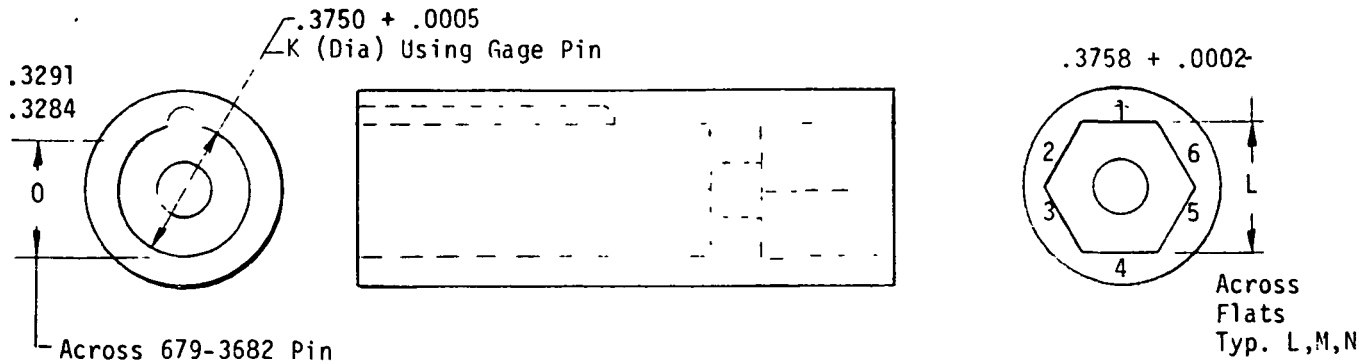
REMARKS (Visual Condition)

Hex ball shows massive signs of yielding. Load mark from CW twist is quite obvious.

*Dutch key dimple on hex is pushed up from load. Hex housing is also burnished.



Hex Ball 679-3628
B/P Dimensions & Tolerances
Shown for Reference

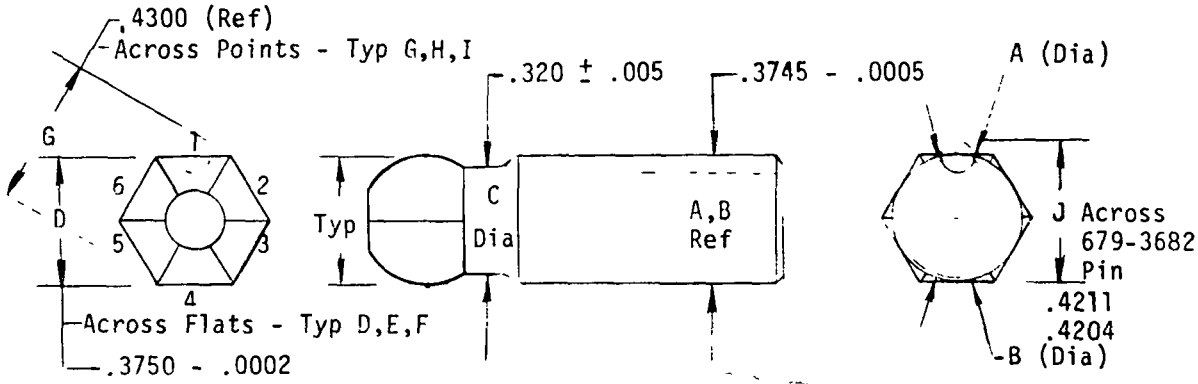


Hex Ball Housing 679-3629
B/P Dimensions & Tolerances
shown for reference

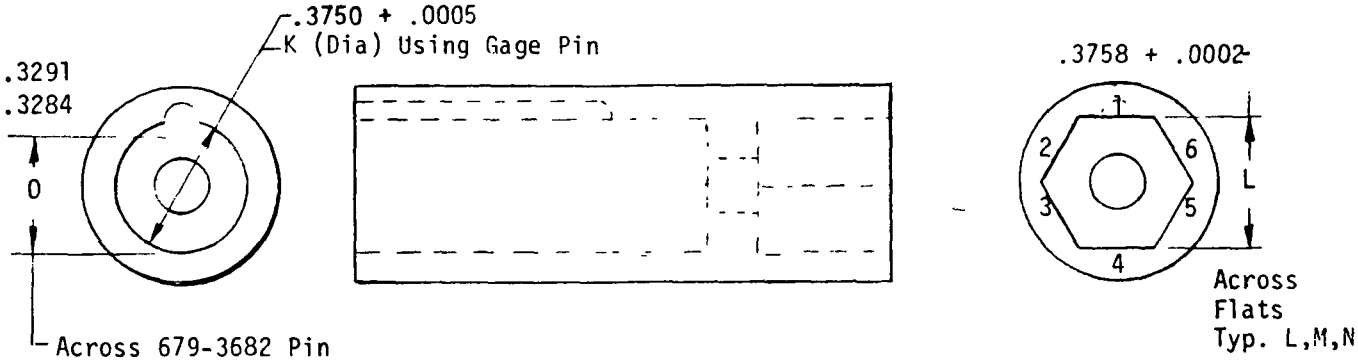
FIGURE 1

Date 8/30
Hex Ball Specimen No. 2
Hex Ball Housing Specimen No. 2
Run No. 20

DIMENSION	PRE-TEST VALUE	POST-TEST VALUE	REMARKS (Visual Condition)
A	0.3746	0.3754	
B	0.3746	0.3744	
C	0.3190	0.3180	
D (1 to 4)	0.3750		
E (2 to 5)	0.3750		
F (3 to 6)	0.3748		
G (1,2 to 5,4)	0.4283		
H (2,3 to 6,5)	0.4282		
I (3,4 to 1,6)	0.4278		
J	0.4210		
K	0.3750	0.3750	
L (1 to 4)	0.3750	0.3750	0.3760
M (2 to 5)	0.3750	0.3750	0.3760
N (3 to 6)	0.3750	0.3750	0.3755
O	0.3285	0.3275	



Hex Ball 679-3628
B/P Dimensions & Tolerances
Shown for Reference

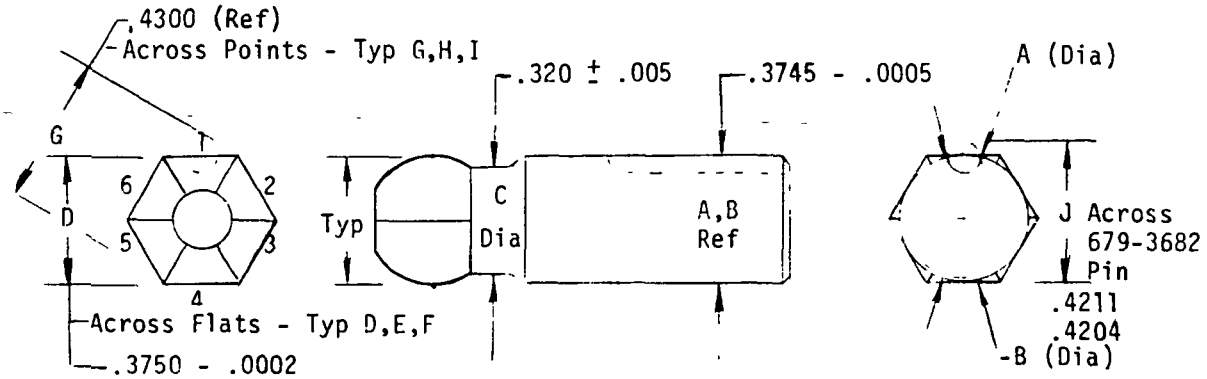


Hex Ball Housing 679-3629
B/P Dimensions & Tolerances
shown for reference

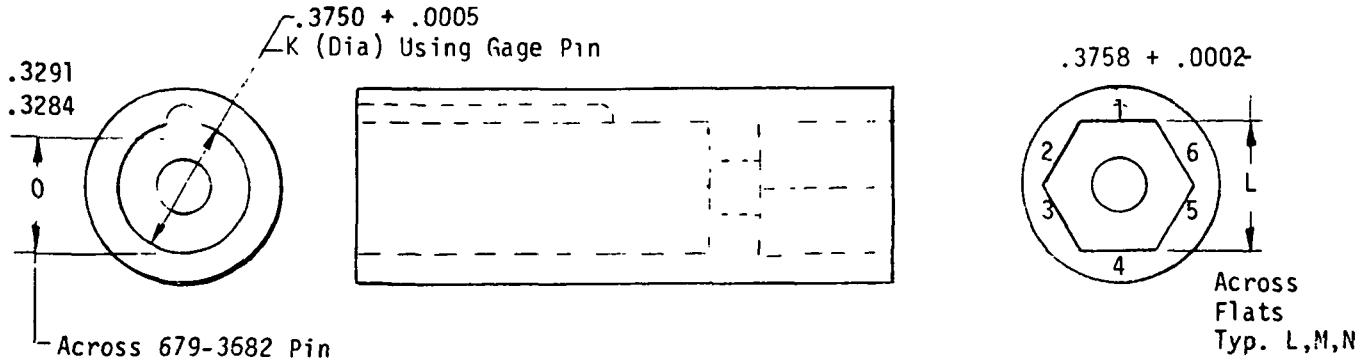
FIGURE 1

Date 8/30
Hex Ball Specimen No. 3
Hex Ball Housing Specimen No. 3
Run No. 21

DIMENSION	PRE-TEST VALUE	POST-TEST VALUE	REMARKS (Visual Condition)
A	0.3743		
B	0.3743		
C	0.3200		
D (1 to 4)	0.3757		
E (2 to 5)	0.3756		
F (3 to 6)	0.3758		
G (1,2 to 5,4)	0.4300		
H (2,3 to 6,5)	0.4300		
I (3,4 to 1,6)	0.4302		
J	0.4204		
K	0.3750		
L (1 to 4)	0.3750		
M (2 to 5)	0.3750		
N (3 to 6)	0.3750		
O	0.3280		



Hex Ball 679-3628
B/P Dimensions & Tolerances
Shown for Reference

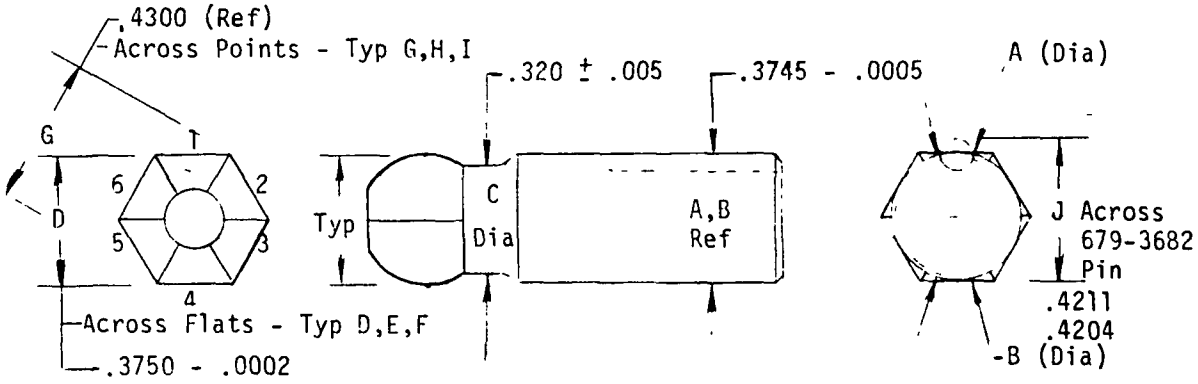


Hex Ball Housing 679-3629
B/P Dimensions & Tolerances
shown for reference

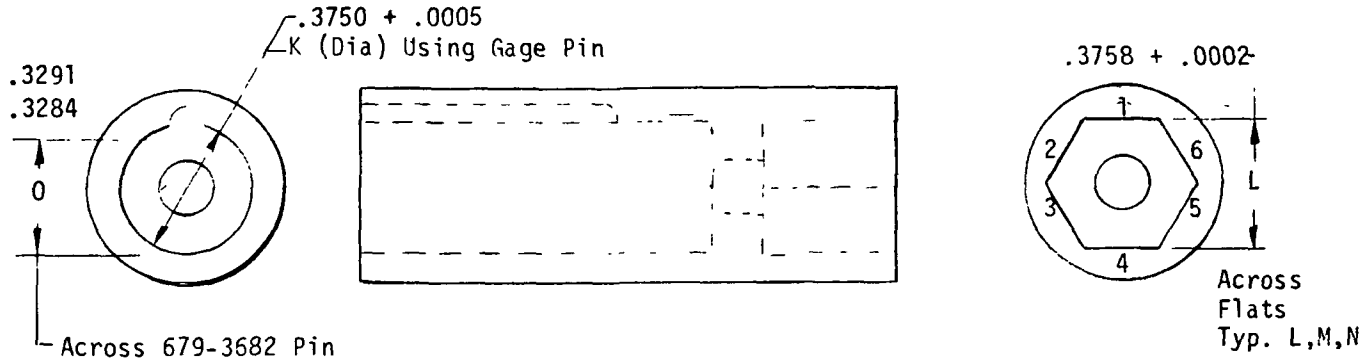
FIGURE 1

Date 8/30
Hex Ball Specimen No. 4
Hex Ball Housing Specimen No. 4
Run No. 22

DIMENSION	PRE-TEST VALUE	POST-TEST VALUE	REMARKS (Visual Condition)
A	0.3766		
B	0.3745		
C	0.3210		
D (1 to 4)	0.3754		
E (2 to 5)	0.3754		
F (3 to 6)	0.3753		
G (1,2 to 5,4)	0.4298		
H (2,3 to 6,5)	0.4300		
I (3,4 to 1,6)	0.4300		
J	0.4208		
K	0.3750		
L (1 to 4)	0.3750		
M (2 to 5)	0.3750		
N (3 to 6)	0.3750	0.3760	
O	0.3285	0.3255	



Hex Ball 679-3628
B/P Dimensions & Tolerances
Shown for Reference

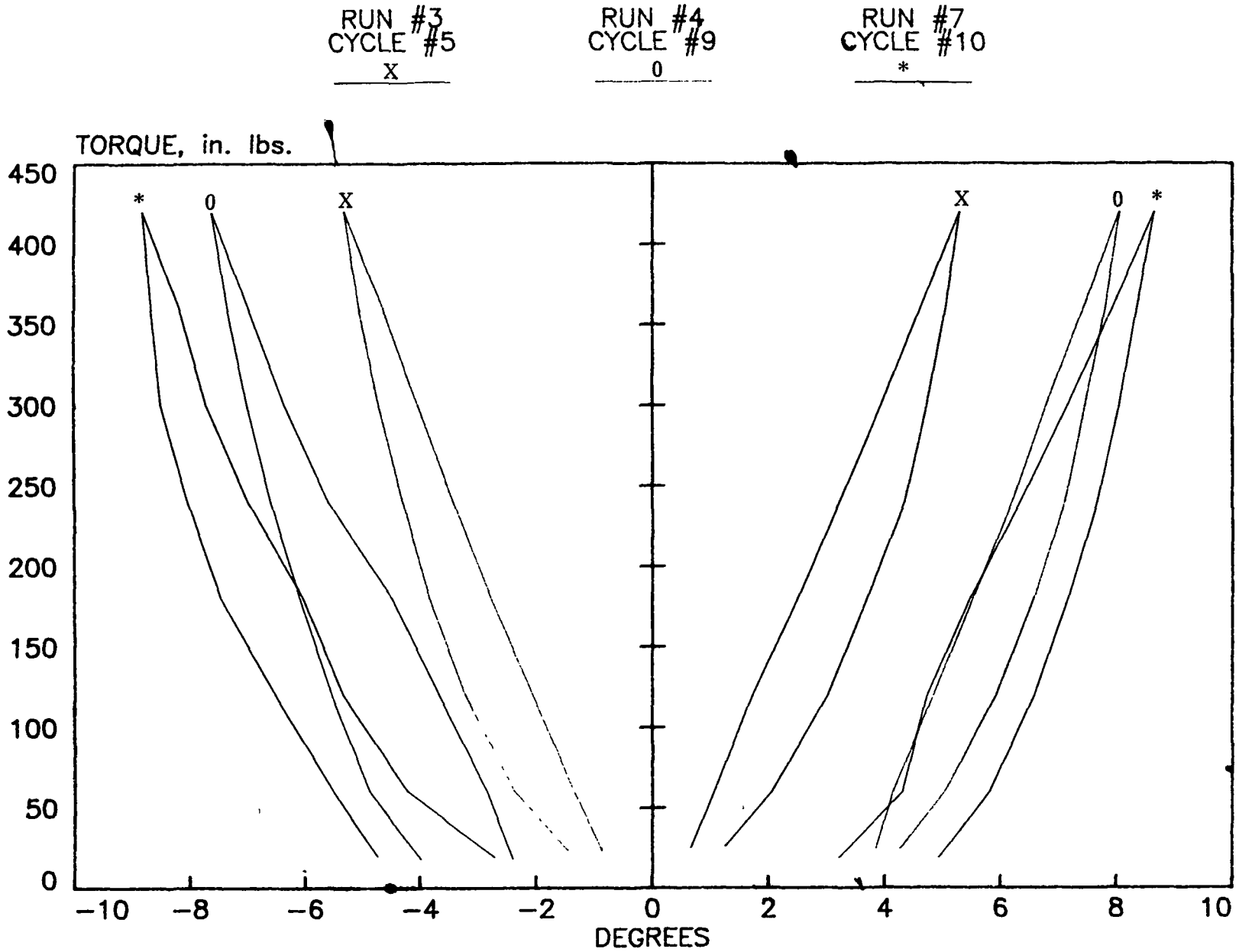


Hex Ball Housing 679-3629
B/P Dimensions & Tolerances
shown for reference

APPENDIX E

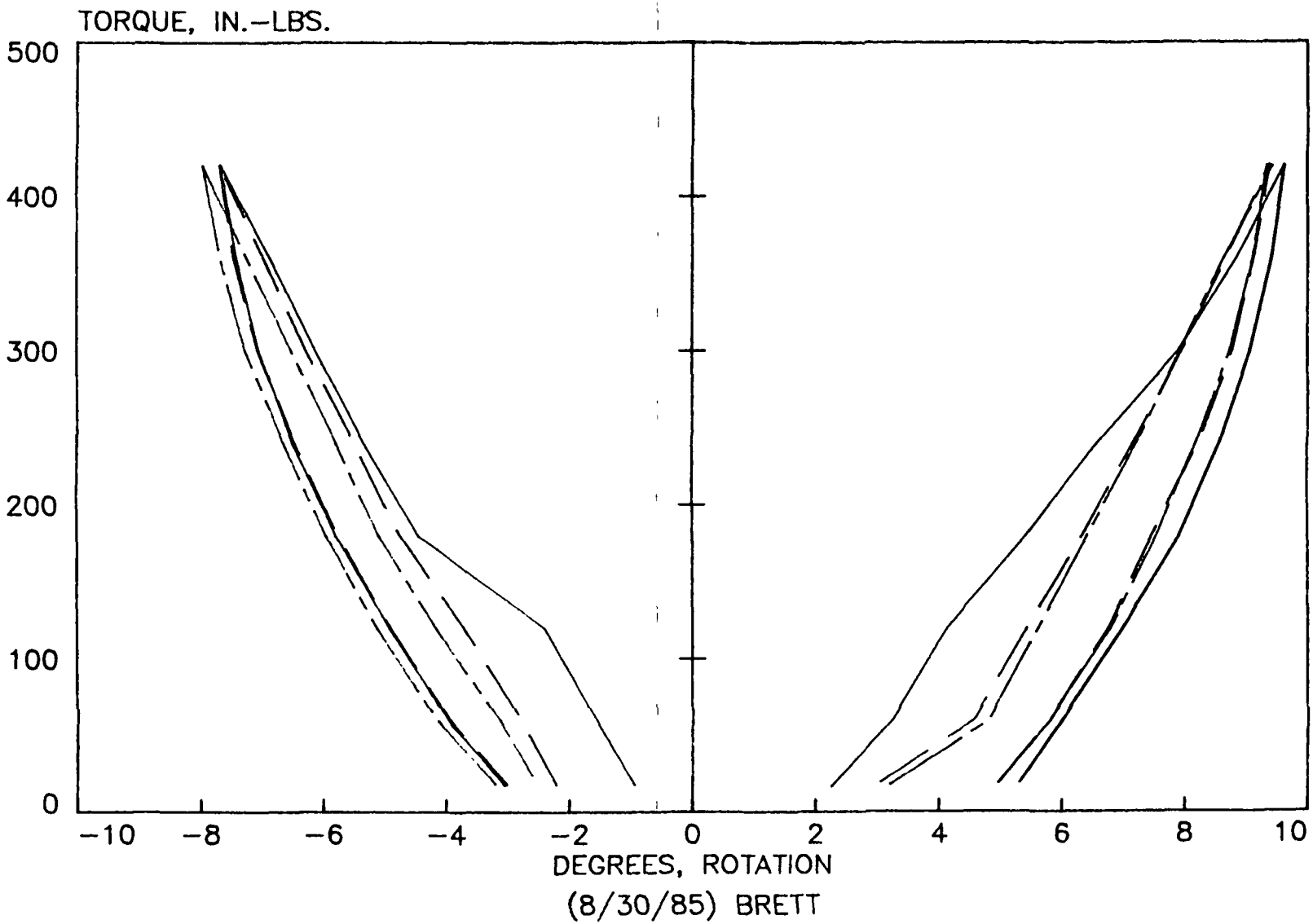
COMPOSITE PLOTS OF DURABILITY CYCLES

HEX BALL TORQUE TEST COMPARISON



HEX BALL TORQUE TEST COMPARISON FOR SPACE TELESCOPE

RUN 10 CYCLE 4 ——— RUN 11 CYCLE 10 — — RUN 14 CYCLE 10 — — —

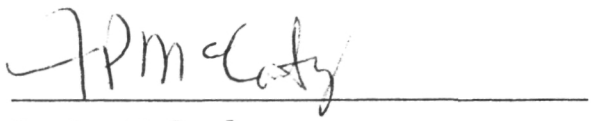


APPROVAL

HEX BALL TORQUE TEST

By B. A. Robinson and C. L. Foster

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.



A. A. McCool
Director, Structures and Propulsion Lab.

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